ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY
AND ASTRONOMICAL PHYSICS

VOLUME III JANUARY 1896 NUMBER 1

ACTION OF THE EDITORIAL BOARD OF THE ASTROPHYSICAL JOURNAL WITH REGARD TO STANDARDS IN ASTROPHYSICS AND SPECTROSCOPY.

At the Congress of Astronomy and Astrophysics, held in Chicago in the summer of 1893, a committee was appointed by the Section of Astrophysics to consider and report upon the advisability of adopting certain astrophysical standards. The members of this committee, on account of the numerous duties devolving upon them during the sessions of the congresses, were unable to report upon the matter, and nothing was accomplished at that time.

The first annual meeting of the board of editors of The Astrophysical Journal, held in New York on November 2, 1894, offered another opportunity for the consideration of this subject, and much time was devoted to its discussion. Messrs. Young, Pickering, Rowland, Michelson, Hastings, Keeler and Hale were present. A full report of the meeting was sent to those members of the editorial board who were not able to attend the meeting, viz., Messrs. Cornu, Dunér, Huggins, Tacchini, Vogel, Ames, Campbell, Crew, Frost and Wadsworth, with copies of the following circular:

As a member of the Board of Editors of THE ASTROPHYSICAL JOURNAL, I am in favor of adopting the following standards in the publication of all papers in the JOURNAL:

1. The.....scale of wave-lengths.

2. The.....as the unit in which wave-lengths shall be expressed.

3. The.....as the unit of measurement of motion in the line of sight.

4. That nomenclature for the lines of the hydrogen series in which the lines are designated thus:.....

5. In printing maps of spectra the.....end shall be placed on the right.

6. In printing tables of wave-lengths, the.....wave-length shall be placed at the top.

(Signature).....

I am in favor of adopting the standards named above, not only in THE ASTROPHYSICAL JOURNAL, but also in all other publications in which they might properly find a place.

(Signature).....

REMARKS:

Votes having been received from all of the editors, the results were presented at the second annual meeting of the board of editors, held at the Harvard College Observatory on October 17 and 18, 1895. The action of the previous year was then confirmed, and the results ordered published.

The *Rowland Scale of Wave-lengths*, as represented by the wave-length tables now being published in THE ASTROPHYSICAL JOURNAL, was adopted by a unanimous vote.

All of the editors, with the exception of Professor Vogel, voted that the *ten millionth of a millimeter*, Ångström's unit, known also as the "tenth-meter," be adopted as the unit in which wave-lengths shall be expressed. Professor Vogel preferred to use the *millionth of a millimeter*, and several others also favored this unit, though they voted with the majority. Professor Cornu's statement of his own position on the question no doubt expresses a not uncommon feeling: "J'accepte le *dix-millionième de millimétre* comme unité pour l'expression des longueurs d'onde, mais c'est *uniquement* parceque la grande majorité des physiciens et astronomes l'emploient dans leurs

publications. Je regrette vivement que l'on ait abandonné l'idée si simple des promoteurs du système mètrique, qui consistait à procéder dans le choix des multiples ou sous-multiples par des *puissances de 1000.* Les préfixes *micro* et *méga*, designant $\frac{1}{1000000}$ et 1000000 ou $10^{\pm 6}$, proposés par les promoteurs du système C. G. S., étaient excellents. Mais eux-mêmes ont abandonné cette voie: après avoir choisi l'*Ohm* 10^{9} unité C. G. S. de resistance ils ont maladroitement adopté le *Volt* 10^{8} unité C. G. S. de potential, dêtruisant ainsi de leurs propres mains la symetrie de la loi de Ohm et se condamnant à accepter l'*Ampère* 10^{-1} C. G. S. comme unité de courant. . . . . "

The *kilometer* was unanimously adopted as the unit to be used in measurements of motion in the line of sight.

The nomenclature proposed by Vogel and Huggins for the hydrogen series, in which the lines are designated $H\alpha$, $H\beta$, $H\gamma$, etc., beginning at the red end and continuing through the entire series, was unanimously adopted.

With the exception of Professors Vogel and Campbell, all of the editors favored printing maps of spectra with the red end on the right, and tables of wave-lengths with the shorter wave-lengths at the top. Professor Vogel preferred the opposite arrangement in each case. Professor Campbell stated that he had no preference, but agreed to follow the decision of the Board.

All of the editors favored the use of the standards for which they had voted, not only in THE ASTROPHYSICAL JOURNAL, but also in all other publications of a similar character.

It is greatly to be hoped that the action of the majority, which has been accepted in THE ASTROPHYSICAL JOURNAL from the outset, will be concurred in by all astronomers, astrophysicists and physicists, and adopted in their publications.

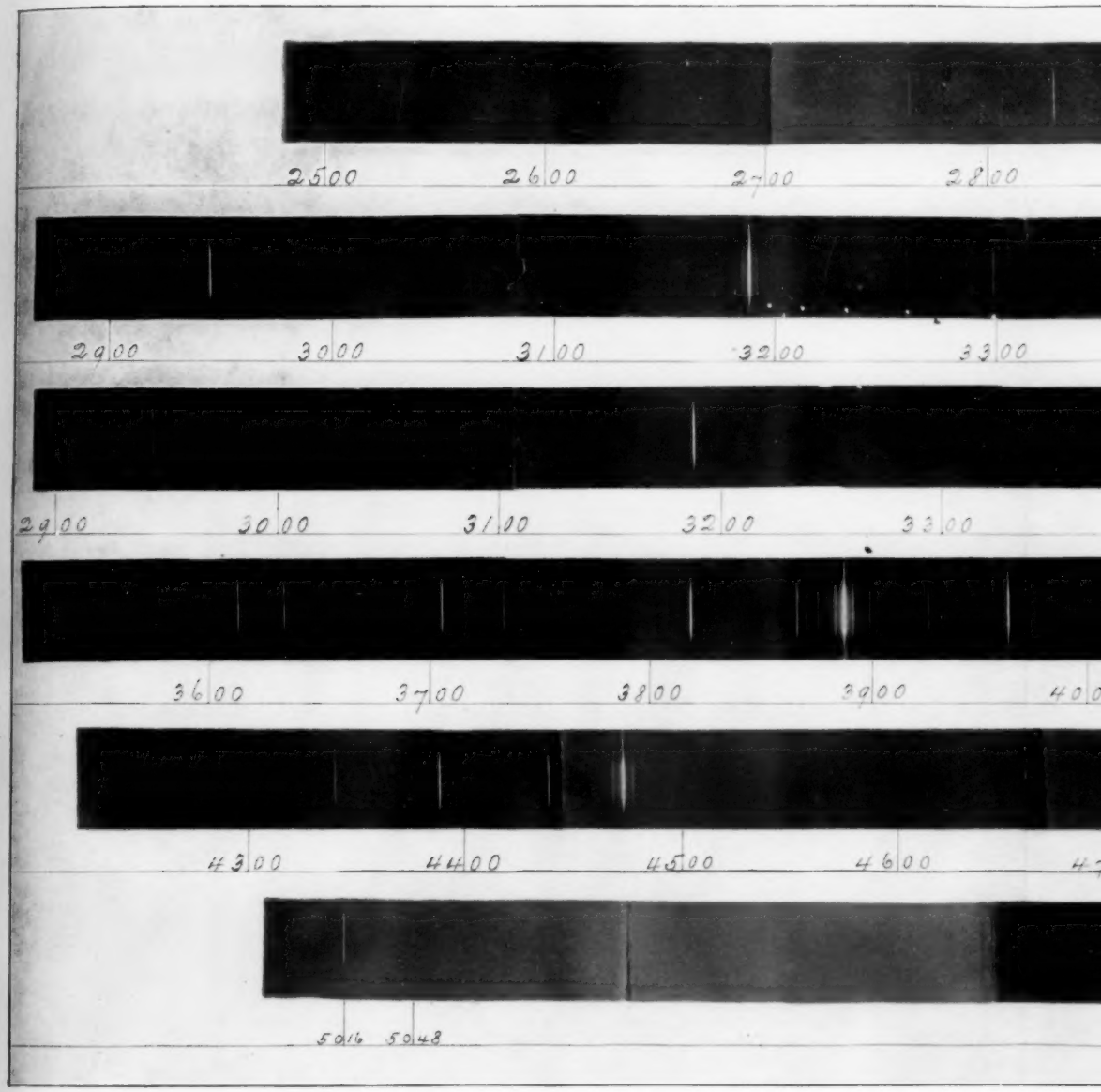
ON THE SPECTRUM OF CLÈVEITE GAS.[1]

By C. RUNGE AND F. PASCHEN.

THE results of this investigation have already been published in papers communicated to the Berlin Academy of Sciences and the British Association. The determinations of the wave-lengths there presented were, however, only preliminary, and many important details were omitted. The final values resulting from a complete examination of our plates are now given, together with a full report on our experiments and on the conclusions arrived at. The gas was obtained by boiling pulverized clèveite from Moss in dilute sulphuric acid. Before introducing the powder into the flask care was taken to expel all air by the vapor of the boiling sulphuric acid. The gas, which was evolved slowly, was collected over a solution of caustic potash and mixed with an abundance of oxygen. It was sparked for several days until the volume, which at first decreased considerably, was not further diminished by a whole days sparking. The sparks showed the spectrum of clèveite gas from the beginning. The oxygen was absorbed by admitting a solution of pyrogallol to the solution of caustic potash and the remaining gas was brought into a vessel, previously exhausted, containing phosphoric acid. The vessel was provided with a small chamber that could be closed by stopcocks and served to separate from the supply of gas a small quantity with which to fill the vacuum tubes. The tubes were made as shown in Fig. 1. *b* is a window of glass, quartz or fluor-spar, according to the purpose, fastened with sealing wax. *C*,*C* are two cylinders of aluminum foil, each pressing against two platinum wires (*p*,*p*). This arrangement of the electrodes is a plan devised by Rowland.[2] It allows stronger currents to pass

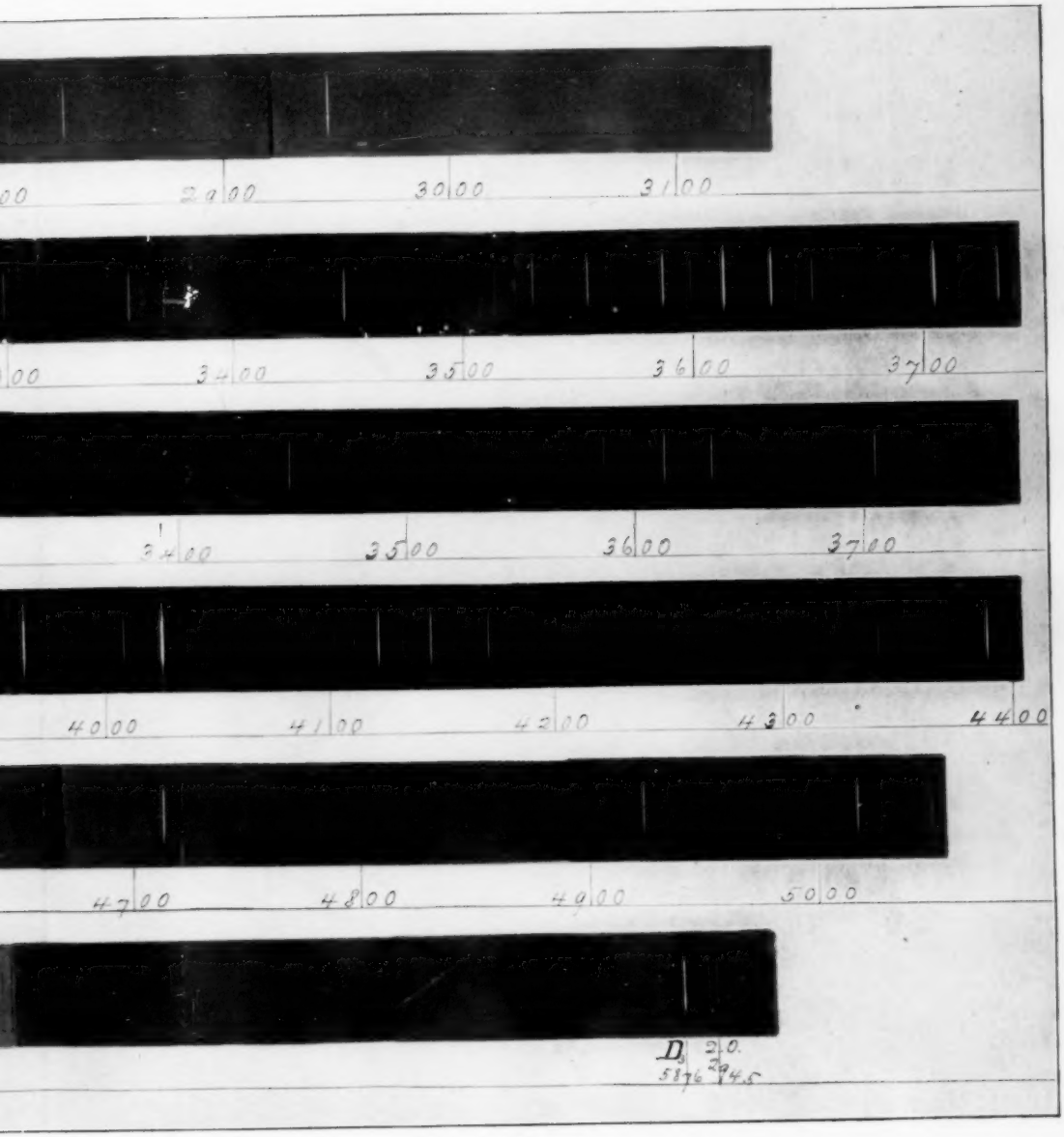
[1] *Sitz. d. K. Akad. d. W. Berlin*, July, 1895, pages 639 and 759. A translation of this paper is published in *Phil. Mag.* September, 1895. See also a paper read before the British Association at Ipswich. *Nat.* **52**, 520, Sept. 26, 1895.

[2] AMES, *Phil. Mag.* **30**, 1890.



PHOTOGRAPH OF THE SPECTRUM OF CLÈVEITE GAS TAKEN IN THE FI

There are some impurities visible, principally hydrogen and traces of the cyanogen band 3883 a
on either side. Two photographs are given of the



N THE FIRST ORDER OF A LARGE ROWLAND CONCAVE GRATING.

gen band 3883 and of nitrogen bands. The strong lines are accompanied by "ghosts"
re given of the region from λ2900 to λ3700.

through the tube without bursting the glass[1] and therefore gives greater brightness than the ordinary plan. At the same time the tube may be used end-on.

The tube is first completely exhausted and dried at the pump. After that a strong induction current is passed through it, the direction of the current being frequently reversed. At the same time the tube is heated with a Bunsen burner, especially in the capillary part and in the region of the electrodes, to as high a temperature as it will bear, and the gas which is evolved is removed by the pump from time to time. This is continued

FIG. 1.

until the tube will not transmit even a strong induction current and the last phosphorescent glow ceases. It is then filled with the gas, and an induction current, the direction of which is frequently reversed, is again allowed to pass. Hydrogen is evolved again as a rule. The tube is then again heated, sparked and exhausted, and this treatment is continued until hydrogen, the most persistent impurity, no longer shows its lines in spite of strong heating and powerful induction currents. About half of the tubes filled in this manner and sealed off when in this condition, remain good for a long time and show the hydrogen lines and other impurities only dimly if at all. A tube may be considered good, if it shows the line 7282 as clearly as or better than the red hydrogen line 6563.

Almost all the stronger lines were interpolated directly from Rowland's standard wave-lengths of iron and sodium lines. The iron lines were obtained by placing two iron electrodes close

[1] The current was taken from a storage battery of six cells. The strength of the primary current was from one to three ampères.

before the slit. The vacuum tube was arranged end-on, and an image of the narrow part was thrown on to the slit so that the rays passed through the iron spark. For accurate determinations we found it necessary to screen off the light from all those parts of the slit that were not fully illuminated by both light sources. The spectrum of a Rowland concave grating[1] being astigmatic, the middle of a line may be slightly shifted by superposed astigmatic images of other parts of the slit. But if both light sources illuminate the same parts of the slit the lines of both sources will be affected equally, and the wave-lengths of one source may be safely referred to those of the other. The sodium lines used as standards were the D lines and the next pair of the principal series at 3303. These lines are emitted from the vacuum tube as soon as the glass gets sufficiently heated. They are very suitable as standards, being extremely narrow and symmetrical. One cannot say the same of all the iron spark lines, and we think that we should have been able to increase the accuracy of our determinations in some degree if we could have used finer standards. The exposures have necessarily varied widely. Very bright lines like 3889 can be photographed in a few seconds, while to bring out the end of a series we have in some cases exposed all night long. A good induction coil with a reliable break was indispensable for this purpose, and we are greatly indebted to Mr. Ernest Porter, who was kind enough to place at our disposal an induction coil made by himself, which works admirably. We did not take pains to place the camera in the normal of the grating. Thus the scale on the plates does not vary quite so slowly as it would have done had we employed Rowland's method of mounting the grating. But the scale was sufficiently constant for the short strip of the spectrum covered by a single series of measures. The lines were always interpolated linearly from a number of standard wave-lengths by the method of least squares. At the same time this method gives us the mean error of a single determination, assuming the stand-

[1] The one we used has a ruled surface of 6 inches, 20,000 lines to the inch and a radius of curvature of 6.5 meters.

ard values to be absolutely correct, and, on the supposition that the measured clèveite line is as fine as the standard lines, its mean error is the same. If it is measured on several plates the weight of each determination is taken inversely proportional to the square of the mean error. The weight of the mean is equal to the sum of the weights of the single determinations, and as the mean error is inversely proportional to the square root of the weight, we can calculate the mean error of the mean from the mean error of the single determinations. This is one way of calculating the mean error of the mean; another method is to calculate it from the differences between the single determinations and their mean. The first value would not be influenced by a constant error in one of the plates, but the second value would. If the two agree one may therefore conclude that there is either no constant error or the same constant error in all the plates. If they do not agree it becomes probable that either there is a constant error in some of the plates or the clèveite line has not been measured with the same accuracy as the standard lines. The two values are given in the table, and the accuracy of the determinations is indicated by the fact that they agree well on the whole. The plates were measured on an "Abbe Comparator" manufactured by Zeiss of Jena. The errors due to this instrument are certainly only a fraction of the error due to the lines not being more accurately defined. With a fine object the error of the instrument is less than $0^{mm}.001$, which in the first order of our Rowland grating corresponds to about 0.002 tenth-meters.

Special care has been taken to determine the distance between the components of the double lines. They were photographed in the second and third orders, and the distance was measured as accurately as possible. The double line 7065 was not photographed but measured by eye observations with a micrometer. The following table contains all the double lines. The first column gives the wave-lengths as they were determined by interpolation from Rowland's standards or indirectly from lines determined from Rowland's standards. The second column contains the difference of these wave-lengths, the third the mean

TABLE OF WAVE-LENGTHS.

Wave-length	Intensity[1]	Mean Error I	Mean Error II	Number of Plates	Number of Determinations	Remarks
2663.3	< 1	....	....	2	2	*
2677.2	< 1	....	....	3	3	*
2696.230	< 1	0.013	....	1	1	
2723.275	1	0.010	0.002	3	3	†
2763.900	2	0.008	0.013	3	4	†
2829.173	4	0.006	0.006	3	4	†
2945.220	6	0.003	0.004	7	8	† and from the sodium lines D_1, D_2. In second order the line is close to D_2.
3176.6	< 1	....	....	1	1	* Very faint, doubtful.
3187.830	8	0.006	0.010	4	4	†
3196.81	< 1	....	....	1	1	* Faint.
3211.626	< 1	....	0.011	1	2	*
3231.327	< 1	....	0.004	3	4	Determined from sodium lines in Rowland's standards, from neighboring clèveite lines and indirectly.
3258.336	< 1	....	0.005	3	3	Determined from sodium lines in Rowland's standards, from neighboring clèveite lines and indirectly.
3296.900	< 1	....	0.008	3	3	Determined from iron and sodium lines in Rowland's standards and also from neighboring clèveite lines.
3354.667	1	0.004	0.005	5	5	Determined from iron and sodium lines in Rowland's standards.
3447.734	2	0.004	0.004	4	5	†
3456.9	< 1	....	....	1	..	Doubtful
3461.4	< 1	....	....	1	..	Doubtful
3466.04	< 1	0.020	0.004	1	2	
3471.93	< 1	0.016	0.02	1	3	
3479.10	< 1	0.016	0.01	1	3	
3481.6	....	....	....	1	1	Doubtful
3487.87	< 1	0.016	0.004	1	3	*
3490.77	< 1	0.02	0.01	1	2	*
3498.78	< 1	0.014	0.02	4	5	*
3502.47	< 1	0.02	0.02	1	3	*
3512.65	< 1	0.013	0.016	5	6	*
3517.48	< 1	0.014	0.02	2	4	*
3530.646	< 1	0.015	0.008	6	8	*
3536.963	< 1	0.006	0.019	3	3	*
3554.594	1	0.014	0.001	2	2	†
3554.725	< 1	....	....	1	1	Faint companion of 3554.594, from which its position was determined.
3563.125	< 1	0.008	0.006	3	4	*
3587.426	2	0.004	0.004	5	5	†
3587.570	< 1	0.004	0.006	5	5	†
3599.472	< 1	0.004	0.007	3	3	†

* Determined from neighboring clèveite lines.

† Determined from iron lines in Rowland's table of standard wave-lengths.

[1] Much weight must not be given to the numbers 15, 10, 9, ... , 2, 1 and < 1 estimating the intensity. The energy of the light might just as well be supposed proportional to the squares or the third powers or any other function of the given numbers.

TABLE OF WAVE-LENGTHS.—*Continued.*

Wave-length	Intensity	Mean Error		Number of Plates	Number of Determinations	Remarks
		I	II			
3599.610	< 1	....	....	1	1	Faint companion of 3599.472, from which its position was determined.
3613.785	3	0.004	0.002	2	2	
3634.393	2	0.003	0.002	4	5	
3634.523	< 1	0.003	0.004	4	5	
3652.121	1	0.003	0.006	3	3	
3652.269	< 1	0.003	0.005	2	2	†
3705.151	3	0.002	0.001	5	7	
3705.287	< 1	0.002	0.002	5	7	
3733.004	1	0.002	0.007	3	3	
3733.142	< 1	0.002	0.004	3	3	
3756.24	< 1	....	....	1	1	Determined as in the case of the line 3787.64. Lines weak and diffuse.
3768.95	< 1	....	....	1	2	
3770.72	< 1	....	....	1	2	Determined as in the case of the line 3787.64. The line is weak and diffuse, and could be seen on but one plate, and only with low power. An error of 0.2 is not impossible.
3785.031	< 1	0.007	0.001	2	2	Determined as in case of the line 3805.9.
3787.64	< 1	....	....	1	2	Determined from the neighboring clèveite lines; visible on but one plate, and only with low power. The accuracy is, therefore, much smaller than that of the other determinations.
3805.900	< 1	0.007	0.005	2	2	Determined from lines of the cyanogen band given in Rowland's table of solar spectrum wave-lengths, and from lines measured on other plates based on standards.
3819.751	4	0.002	0.001	3	4	†
3819.899	< 1	0.002	0.004	3	4	†
3833.710	< 1	0.009	0.011	3	3	Determined by lines of the cyanogen band given in Rowland's solar spectrum wave-lengths, and indirectly.
3838.240	< 1	0.010	0.014	2	2	
3867.613	2	0.002	0.002	5	5	†
3867.766	< 1	0.004	....	1	1	†
3871.954	< 1	0.009	0.010	3	3	Determined by lines from Rowland's solar spectrum wave-lengths and indirectly.
3878.330	< 1	0.009	0.004	3	3	
3888.785	10	0.002	0.004	7	7	Determined from Rowland's standards and also indirectly. Difficult line on account of its enormous energy. Ghosts of the eighth order generally visible on both sides. The ghosts were used in the determination.
3926.678	1	0.005	0.005	4	5	Determined from Rowland's standards, and on one plate indirectly from lines based on Rowland's standards.
3936.064	< 1	0.008	0.011	2	2	Determined indirectly from lines based on Rowland's standards.

TABLE OF WAVE-LENGTHS.

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3176.6	< 1	....	....	1	1	* Very faint, doubtful.
3187.830	8	0.006	0.010	4	4	†
3196.81	< 1	....	....	1	1	* Faint.
3211.626	< 1	....	0.011	1	2	*
3231.327	< 1	....	0.004	3	4	Determined from sodium lines in Rowland's standards, from neighboring clèveite lines and indirectly.
3258.336	< 1	....	0.005	3	3	Determined from sodium lines in Rowland's standards, from neighboring clèveite lines and indirectly.
3296.900	< 1	....	0.008	3	3	Determined from iron and sodium lines in Rowland's standards and also from neighboring clèveite lines.
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3456.9	< 1	....	....	1	..	Doubtful
3461.4	< 1	....	....	1	..	Doubtful
3466.04	< 1	0.020	0.004	1	2	*
3471.93	< 1	0.016	0.02	1	3	*
3479.10	< 1	0.016	0.01	1	3	*
3481.6	....	....	....	1	1	Doubtful
3487.87	< 1	0.016	0.004	1	3	*
3490.77	< 1	0.02	0.01	1	2	*
3498.78	< 1	0.014	0.02	4	5	*
3502.47	< 1	0.02	0.02	1	3	*
3512.65	< 1	0.013	0.016	5	6	*
3517.48	< 1	0.014	0.02	2	4	*
3530.646	< 1	0.015	0.008	6	8	*
3536.963	< 1	0.006	0.019	3	3	*
3554.594	1	0.014	0.001	2	2	†
3554.725	< 1	....	....	1	1	Faint companion of 3554.594, from which its position was determined.
3563.125	< 1	0.008	0.006	3	4	*
3587.426	2	0.004	0.004	5	5	†
3587.570	< 1	0.004	0.006	5	5	†
3599.472	< 1	0.004	0.007	3	3	†

* Determined from neighboring clèveite lines.

† Determined from iron lines in Rowland's table of standard wave-lengths.

[1] Much weight must not be given to the numbers 15, 10, 9, ... , 2, 1 and < 1 estimating the intensity. The energy of the light might just as well be supposed proportional to the squares or the third powers or any other function of the given numbers.

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Wave-length	Intensity	Mean Error		Number of Plates	Number of Determinations	Remarks
		I	II			
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3613.785	3	0.004	0.002	2	2	
3634.393	2	0.003	0.002	4	5	
3634.523	< 1	0.003	0.004	4	5	
3652.121	1	0.003	0.006	3	3	
3652.269	< 1	0.003	0.005	2	2	†
3705.151	3	0.002	0.001	5	7	
3705.287	< 1	0.002	0.002	5	7	
3733.004	1	0.002	0.007	3	3	
3733.142	< 1	0.002	0.004	3	3	
3756.24	< 1	....	....	1	1	Determined as in the case of the line 3787.64. Lines weak and diffuse.
3768.95	< 1	....	....	1	2	
3770.72	< 1	....	....	1	2	Determined as in the case of the line 3787.64. The line is weak and diffuse, and could be seen on but one plate, and only with low power. An error of 0.2 is not impossible.
3785.031	< 1	0.007	0.001	2	2	Determined as in case of the line 3805.9.
3787.64	< 1	....	....	1	2	Determined from the neighboring clèveite lines; visible on but one plate, and only with low power. The accuracy is, therefore, much smaller than that of the other determinations.
3805.900	< 1	0.007	0.005	2	2	Determined from lines of the cyanogen band given in Rowland's table of solar spectrum wave-lengths, and from lines measured on other plates based on standards.
3819.751	4	0.002	0.001	3	4	†
3819.899	< 1	0.002	0.004	3	4	†
3833.710	< 1	0.009	0.011	3	3	Determined by lines of the cyanogen band given in Rowland's solar spectrum wave-lengths, and indirectly.
3838.240	< 1	0.010	0.014	2	2	
3867.613	2	0.002	0.002	5	5	†
3867.766	< 1	0.004	....	1	1	†
3871.954	< 1	0.009	0.010	3	3	Determined by lines from Rowland's solar spectrum wave-lengths and indirectly.
3878.330	< 1	0.009	0.004	3	3	
3888.785	10	0.002	0.004	7	7	Determined from Rowland's standards and also indirectly. Difficult line on account of its enormous energy. Ghosts of the eighth order generally visible on both sides. The ghosts were used in the determination.
3926.678	1	0.005	0.005	4	5	Determined from Rowland's standards, and on one plate indirectly from lines based on Rowland's standards.
3936.064	< 1	0.008	0.011	2	2	Determined indirectly from lines based on Rowland's standards.

TABLE OF WAVE-LENGTHS.—*Continued.*

Wave-length	Intensity	Mean Error		Number of Plates	Number of Determinations	Remarks
		I	II			
3964.875	4	0.004	0.003	4	4	†
4009.417	1	0.003	0.002	3	3	†
4024.136	< 1	0.004	0.006	2	2	†
4026.342	5	0.003	0.005	3	3	†
4026.512	< 1	0.003	0.008	3	3	†
4120.973	3	0.006	0.003	3	4	† and partly from Rowland's table of solar spectrum wave-lengths.
4121.143	< 1	0.006	0.003	3	4	
4143.919	2	0.006	0.003	3	4	
4169.131	1	0.007	0.006	2	2	
4388.100	3	0.004	0.004	4	4	†
4437.718	1	0.004	0.005	4	4	†
4471.646	6	0.004	0.005	4	4	†
4471.858	< 1	0.004	0.006	4	4	†
4713.252	3	0.011	0.014	4	4	Determined from second order iron lines from Rowland's table of standards.
4713.475	< 1	0.016	0.004	2	2	
4922.096	4	0.013	0.010	5	5	Determined from second order iron lines measured by Kayser and Runge, and corrected to agree with Rowland's standards.
5015.732	6	0.006	0.007	4	4	Determined from second order iron lines in Rowland's table of standards.
5047.816	2	0.007	0.007	3	3	
5875.870	10	0.006	0.005	6	9	Determined from second order iron lines and from the D lines, all Rowland's standards.
5876.209	1	0.007	0.004	6	6	
6678.37[1]	6	0.005	0.004	2	2	Determined from the two Rowland standards Na 3302 and 3303 in the second order, and some lines of a nitrogen band previously determined by iron lines from Rowland's table of standards.
7065.48[1]	5	0.025	0.030	1	2	Determined from the helium lines 3587, 3554, 3530 in the second order.
7066.00[1]	< 1	....	0.031	..	..	Determined from 7065.48 by measuring the distance visually with a micrometer in the first order of our large concave grating.
7281.81	3	....	0.05	..	..	Measured visually with a spectrometer in the second, third, and fourth orders ot a plane Rowland grating.
11170	15	....	48.	..	..	Bolometric measurements. See note at the end of this paper.
20400	10	....	80.	..	..	

[1] These lines, 6678.37, 7065.48 and 7066.00, are close to two red argon lines, but they are by no means coincident with them. The wave-lengths of the argon lines are 6677.39 (m. e. 0.08), 7067.55 (m. e. 0.06). Ramsay's suggestion of a constituent common to argon and helium, which was based on the apparent coincidence of these lines, thus lacks confirmation.

error of this difference, the fourth the difference of the wave-lengths measured in higher orders, the fifth the mean error, the sixth the mean of the two differences. The seventh column gives the corresponding differences of wave-numbers in units of the eighth figure. The eighth column will be explained later.

Wave-length	Difference	Mean error	Difference measured in higher orders	Mean error	Mean	Corresponding difference of wave-numbers	
3554.594 3554.725	...	..	131	..	131	1131	.127
3587.426 3587.570	144	7	143	..	143	1111	.130
3599.472 3599.610	...	..	138	..[1]	138	1066	.130
3634.393 3634.523	130	5	144	8	134	1014	.133
3652.121 3652.269	148	8	133	5	143	1072	.134
3705.151 3705.287	136	3	135	5	136	991	.138
3733.004 3733.142	138	8	...	..	138	991	.140
3819.751 3819.899	148	4	148	2	148	1014	.147
3867.613 3867.766	153	4	150	2	151	1009	.151
4026.342 4026.512	170	9	163	1	163	1006	.163
4120.973 4121.143	170	8	170	2	170	1001	.171
4471.646 4471.858	212	8	200	2	201	1005	.203
4713.252 4713.475	223	21	223	2	223	1004	.224
5875.870 5876.209	339	9	343	3	343	993	.348
7065.49 7066.00	...	..	516	6	516	1034	.503
					Mean: 1007 (mean error 3.6)		

It appears that the difference of wave-numbers is the same for all the double lines. The mean is 1007, the deviation from the mean surpassing the mean error only in three cases out of 12. That the difference of wave-numbers is constant we are the more ready to believe from the same fact having been observed in the spectra of many other elements, including Na, K, Rb, Cs, Cu,

[1] The first three differences are doubtful, the lines being difficult to separate.

Ag, Al, In, Tl. If it is constant, then the wave-length differences ought to be those given in the eighth column, and we may be justified in correcting the wave-lengths of the two components of each double line so that the difference becomes equal to the calculated number. Taking account of the different accuracy with which the components have been measured, the following wave-lengths would be arrived at:

WAVE-LENGTHS CORRECTED TO CONSTANT DIFFERENCE OF WAVE-NUMBERS.

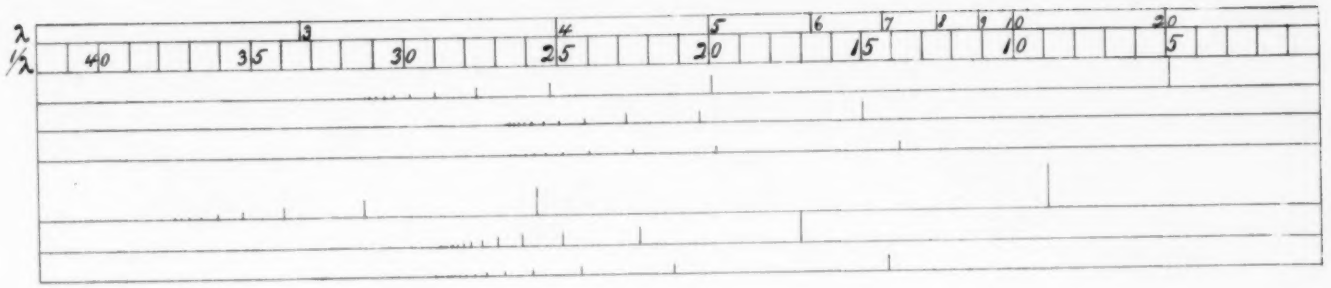
.....	3819.751
.....	3819.898
3554.594	3867.613
3554.721	3867.764
3587.430	4026.344
3587.560	4026.507
3599.472	4120.973
3599.602	4121.144
3634.392	4471.650
3634.525	4471.853
3652.129	4713.252
3652.263	4713.476
3705.150	5875.866[1]
3705.288	5876.214
3733.002	7065.48
3733.142	7065.98

In our former publications we have also given 2764, 2829, 2945, 3188, 3613, 3888, 3965 as double. This appears to have been an error. We have convinced ourselves since that they are single so far as we are able to judge in the second and third order of a grating of 110000 lines, except perhaps the line 3889. In the third order there appears to be a fainter component, the wave-length of which is 0.05 larger.

The distribution of the lines in the spectrum of clèveite gas

[1] This difference between the components of D_3 agrees better than our first determinations with the measurements of Hale in the spectrum of the Sun's limb. Hale finds 0.357, which differs from the value given above by only 0.009. It may be of interest to note that the stronger component of D_3 is clearly seen to be reversed on the photographs as well as by eye observation. But the reversal is so fine that it only shows in the second order.

PLATE III.



shows a beautiful regularity when the lines are separated into six series. In the accompanying figure (Plate III) the lines are drawn to the scale of wave-numbers, the intensity being signified by the length of the lines.

The regularity would be destroyed if the six groups were drawn promiscuously all in one row. We do not think that any one can believe this regular distribution to be accidental, but we can give still better proof of a law connecting the members of each series. The wave-lengths of each series may be calculated from a formula:

$$\frac{1}{\lambda} = A + \frac{B}{n^2} + \frac{C}{n^3}$$

where A, B, C are constants and where n represents the series of whole numbers beginning with 2 or with 3. The last two series consist of double lines. At least all the stronger lines of the two series have been seen to be double. The lines corresponding to shorter wave-lengths become too weak and too diffuse for the duplicity to be recognized, though they are very likely double. There should be two formulæ for each of the last two rows of the drawing, one for the stronger and one for the weaker component. We give only the formula for the stronger component; the other may easily be deduced by subtracting 100.7 from the constant A. For as we have shown above, the difference of wave-numbers of the two components is constant. To calculate the formulæ all the wave-lengths have been reduced to a vacuum according to the determinations of Kayser and Runge,[1] and $\frac{1}{\lambda}$ is calculated to such a number of figures that the number given represents the number of waves that make up one meter *in vacuo*. The differences between the observed and the calculated values might be made still smaller by calculating the constants of the formula not only to suit three consecutive observed values but so as to make all of the deviations as small as possible. But we thought it more instructive to show how accurately all of the wave-numbers may be calculated from three of them.

[1] KAYSER und RUNGE, "Die Dispersion der Luft." *Abh. d. K. Akad. d. W. Berlin*, 1893.

PRINCIPAL SERIES.

$$\text{Wave-number} = 3202986 - 1.09537 \times \frac{10^7}{n^2} + 1.9636 \times \frac{10^5}{n^3}$$

n	Wave-length in air at 20° C. and 760mm	Wave-number observed	Wave-number calculated	Difference	Corresponding difference in tenth-meters	Remarks
14	3176.6 ?	3147127	3147171	−44	+0.04	Doubtful
13	.....[1]	.....	3138261	....	.....	
12	3196.81	3127232	3127032	200	−0.20	
11	3211.626	3112806	3112607	199	−0.21	
10	3231.327	3093828	3093645	183	−0.19	
9	3258.336	3068183	3068024	159	−0.17	
8	3296.900	3032296	3032218	78	−0.08	
7	3354.667	2980082	2980014	68	−0.08	
6	3447.734	2899641	2899626	15	−0.02	
5	3613.785	2766409	These three values determine the constants	0	0.00	
4	3964.875	2521448		0	0.00	
3	5015.732	1993181		0	0.00	
2	20400.	4901...	489106	10..	−42.	The mean error is 80.

[1] This line has not been seen. As the last lines of the series are very faint, they could be brought out only by long exposure. But this broadened the strong line 3188 to such an extent that weak lines in the neighborhood cannot advantageously be searched for.

FIRST SUBORDINATE SERIES.

$$\text{Wave-number} = 2717516 - 1.097587 \times \frac{10^7}{n^2} - 2.726 \times \frac{10^4}{n^3}$$

n	Wave-length in air at 20° C. and 760mm	Wave-number observed	Wave-number calculated	Difference	Corresponding difference in tenth-meters	Remarks
14	3756.24	2661495	2661507	−12	+0.017	
13	3768.95	2652520	2652558	−38	+0.054	
12	3785.031	2641250	2641279	−29	+0.042	
11	3805.900	2626768	2626786	−18	+0.026	
10	3833.710	2607713	2607730	−17	+0.025	
9	3871.954	2581957	2581974	−17	+0.026	
8	3926.678	2545975	2545965	+10	−0.015	
7	4009.417	2493437	2493439	− 2	+0.003	
6	4143.919	2412507	2412504	+ 3	−0.005	
5	4388.100	2278263	These three values determine the constants	0	0.000	
4	4922.096	2031098		0	0.000	
3	6678.37	1496965		0	0.000	

SECOND SUBORDINATE SERIES.

$$\text{Wave-number} = 2716859.5 - 1.088256 \times \frac{10^7}{n^2} - 3.596 \times \frac{10^6}{n^3}$$

n	Wave-length in air at 20° C. and 760 mm	Wave-number observed	Wave-number calculated	Difference	Corresponding difference in tenth-meters	Remarks
13	3770.72	2651274	2650829	+ 445	— 0.63	
12	3787.64	2639431	2639205	+ 226	— 0.33	
11	..... [1]	.....	2624219	.....	.....	
10	3838.240	2604636	2604438	+ 198	— 0.29	
9	3878.330	2577712	2577574	+ 138	— 0.21	
8	3936.064	2539904	2539796	+ 108	— 0.17	
7	4024.136	2484316	2484282	+ 34	— 0.06	
6	4169.131	2397918	These three values determine the constants	0	0.00	
5	4437.718	2252789		0	0.00	
4	5047.816	1980512		0	0.00	
3	7281.81	1372913	1374501	— 1588	+ 8.4	

[1] There is a line at 3809.22, wave-number 2624478, but we believe it to be an impurity, which covers the line of the series. It looks too sharp and somewhat too strong to belong to the series.

PRINCIPAL SERIES.

$$\text{Wave-number} = 3845532.4 - 1.098919 \times \frac{10^7}{n^2} - 1.4507 \times \frac{10^6}{n^3}$$

n	Wave-length in air at 20° C. and 760mm	Wave-number observed	Wave-number calculated	Difference	Corresponding difference in tenth-meters	Remarks
11	2663.3	3753645	3753623	+ 22	— 0.016	
10	2677.2	3734158	3734190	— 32	+ 0.023	
9	2696.230	3707804	3707873	— 69	+ 0.050	
8	2723.275	3670983	3670993	— 10	+ 0.007	
7	2763.900	3617028	3617034	— 6	+ 0.005	
6	2829.173	3533582	3533561	+ 21	— 0.017	
5	2945.220	3394359	These three values determine the constants	0	0.000	
4	3187.830	3136041		0	0.000	
3	3888.785	2570782		0	0.000	The mean
2	11170...	8951...	916897	— 218..	+ 270	error is 48.

FIRST SUBORDINATE SERIES.

$$\text{Wave-number} = 2922435 - 1.098363 \times \frac{10^7}{n^2} - 1.67 \times \frac{10^4}{n^3} \ *$$

n	Wave-length in air at 20° C. and 760 mm	Wave-number observed	Wave-number calculated	Difference	Corresponding difference in tenth-meters	Remarks
19	3456.9 ?	2891943	2892007	— 64	0.08	Doubtful.
18	3461.4 ?	2888193	2888532	— 339	0.41	Doubtful.
17	3466.04	2884327	2884426	— 99	0.12	
16	3471.93	2879433	2879526	— 93	0.11	
15	3479.10	2873500	2873614	— 114	0.14	
14	3487.87	2866274	2866390	— 116	0.14	
13	3498.78	2857337	2857436	— 99	0.12	
12	3512.65	2846056	2846150	— 94	0.12	
11	3530.646	2831549	2831649	— 100	0.13	
10	3554.594	2812473	2812582	— 109	0.14	
9	3587.426	2786734	2786812	— 78	0.10	
8	3634.393	2750723	2750783	— 60	0.08	
7	3705.151	2698192	2698231	— 39	0.05	
6	3819.751	2617244	2617257	— 13	0.02	
5	4026.342	2482956	These three values determine the constants	0	0.00	
4	4471.646	2235697		0	0.00	
3	5875.870	1701413		0	0.00	

*It is curious that while in the other five series the first line always corresponds to the smallest positive value of n for which the formula gives a positive value, in this case it does not. Giving n the value 2 we get $\lambda = 57326$. But there is no line there of an intensity corresponding to that of the first member of this series. We particularly searched for it, and are sure that between $\lambda = 20400$ and $\lambda = 100000$ there is no line the energy of which surpasses the heat of the glass tube in this part of the spectrum. See the note at the end.

SECOND SUBORDINATE SERIES.

$$\text{Wave-number} = 2919796.7 - 1.061524 \times \frac{10^7}{n^2} - 8.656 \times \frac{10^6}{n^3}$$

n	Wave-length in air at 20° C. and 760 mm	Wave-number observed	Wave-number calculated	Difference	Corresponding difference in tenth-meters	Remarks
15	3481.6	2871437	2870052	+ 1385	— 1.69	
14	3490.77	2863893	2862483	+ 1410	— 1.72	
13	3502.47	2854327	2853045	+ 1282	— 1.57	
12	3517.48	2842147	2841071	+ 1076	— 1.33	
11	3536.963	2826492	2825564	+ 928	— 1.16	
10	3563.125	2805739	2804988	+ 751	— 0.95	
9	3599.472	2777408	2776871	+ 537	— 0.70	
8	3652.121	2737371	2737027	+ 344	— 0.46	
7	3733.004	2678061	2677923	+ 138	— 0.19	
6	3867.613	2584855	These three values determine the constants	0	0.00	
5	4120.973	2425939		0	0.00	
4	4713.252	2121094		0	0.00	
3	7065.48	1414948	1419733	— 4785	+24.	

The deviations of the calculated values from the observed wave-numbers in most cases exceed the limits of error, but nevertheless we think it is clearly shown that there is a numerical relation connecting all the lines of a series, though the exact law has not yet been found. Series of lines similar to these have been observed in the spectra of many other elements,[1] and formulæ similar to those given above have been calculated. Kayser and Runge have preferred the form

$$\frac{1}{\lambda} = A + \frac{B}{n^2} + \frac{C}{n^4},$$

while the formulæ given above have a term $\frac{C}{n^3}$ instead of $\frac{C}{n^4}$. We have found the agreement decidedly closer with $\frac{C}{n^3}$ and therefore prefer this form, though the difference is not great. Both forms are only approximations to the real law, which is probably represented by an infinite series of negative powers of n.

The second constant B is nearly the same in all six formulæ. Indeed it is nearly the same in all formulæ for all series of lines that have been observed in the spectra of any of the elements. For the hydrogen series, for instance, this constant is 1.096732×10^7. It must have some important physical meaning relating to a quality common to all elements in this state of vibration. It may further be seen from the drawing as well as from the formulæ that the third series approaches the same limit as the second, and that the sixth series approaches the same limit as the fifth. For the constant A is very nearly the same for each pair. We believe that for the exact law the limit towards which the wave-numbers approach should be exactly the same. For the discrepancy which still exists between the two values of A becomes much smaller if the constants are calculated from three wave-numbers nearer the end of the series. Thus, calculating the formula of the sixth series from the wave-numbers corre-

[1] RYDBERG, "Recherches sur la constitution des spectres d'émission des éléments chimiques." *Svenska vetensk. Akad. Handl.* **23**, No. 11. KAYSER und RUNGE. *Abh. d. K. Akad. d. W. Berlin*, 1888–93.

sponding to $n = 9,10,11$ we find for A the value 2921886, while it is 2922435 for the fifth series, so that the calculated limit of the sixth series would be only 0.65 tenth-meters to the less refrangible side of the calculated limit of the fifth series.

This phenomenon of two series of lines approaching the same limit is common to the spectra of all elements in which series of lines have been observed except hydrogen. In all these spectra we find two series of single, double or triple lines apparently approaching the same limit.[1] All the double or triple lines forming two such series have the same difference of wave-numbers. But there is no case in all the eighteen spectra, where series of lines have been observed, of more than two series approaching the same limit. Therefore, we come to the conclusion that clèveite gas consists of two elements, one corresponding to the second and third series (single lines), and the other corresponding to the fifth and sixth series (double lines with constant difference of wave-numbers). If this is true the name *Helium* should be given only to the second element, the spectrum of which includes D_3. The first element Professor Stoney has proposed to call *Parhelium*.[2] In all the spectra of the alkalis there is a third series, in addition to the two that approach the same limit. This third series is very strong; it embraces several lines of the other series between each of its members, and finally runs out on the more refrangible side of the spectrum. It has been called the principal series by Rydberg, and by Kayser and Runge, while the other two have been called subordinate series. Of the two subordinate series one is invariably the stronger. It is called the first subordinate series and the other the second subordinate series. These designations have been extended to the other spectra, where two series of lines approaching the same limit have been observed, and we

[1] In the spectrum of rubidium and cæsium only one member of the "second subordinate series" seems to have been found. The place where it ends therefore cannot be deduced.

[2] We shall for convenience use this name in the following. We are well aware that, although strong reason for supposing the gas to consist of two constituents has been given by our work, conclusive proof is still wanting.

shall also apply them to the spectra of helium and parhelium. The two remaining series we take to be the two principal series corresponding, the one to helium and the other to parhelium, as they show the same characteristics as the principal series in the spectra of the alkalis. As the two subordinate series of helium are stronger than those of parhelium, we take the stronger of the two (the fourth in the drawing), to be the principal series of helium. The first three rows in the drawing represent the spectrum of parhelium, and the other three that of helium. Both spectra now closely resemble any of the spectra of the alkalis. We also note that, as in the spectra of the alkalis, the first subordinate series has a smaller spread than the second, corresponding intervals being smaller for the first; or, as we might also express it, the formula of the first subordinate series has a smaller value of C. The lines are now all disposed of in the two systems, which we think justifies the conclusion that the gas does not contain more than these two constituents.

From the analogous fact in the spectra of the alkalis, we should expect the first line of the principal series of helium to be a double line, with the same difference of wave-numbers as the double lines in the subordinate series. The following lines of the principal series should also be double lines, but the differences of wave-numbers should decrease rapidly, *e. g.*, from the first to the second line in the proportion of about three to one. It is impossible to test this conclusion as to the first line, for the bolometer is not sufficiently sensitive to bear a dispersion that would separate the components. But, as to the second line, the possibility of the test is just within reach. The difference of wave-numbers should be about one-third of 100.7, which for the line 3889 comes to 0.051 tenth-meters. Indeed, on two of our photographs of the line in the third order a faint component is to be seen on the less refrangible side, the distance of which we measured as 0.057 on one plate, and 0.051 on the other. But we feel not quite sure of the result, because on some of the plates spurious lines have made their appearance, due probably to defects in the apparatus.

In the spectra of the alkalis, the distance between the components of the double lines increases with the atomic weight, in such a manner that the difference of wave-numbers is roughly proportional to the square of the atomic weight.

	Difference of wave-numbers	Atomic weight	Difference divided by square of atomic weight
Na	1710	23	3.1
K	5680	39	3.7
Rb	23440	85	3.2
Cs	54500	133	3.1

If helium followed the same law, the atomic weight could be calculated from the difference of wave-numbers of the double lines, which we found to be 100.7. If the atomic weight is x, we should have 100.7 between about $3.1 \times x^2$ and $3.7 \times x^2$, that is, x between about 5.7 and 5.2. As clèveite gas has been found to be monatomic, with a density of about 2 (hydrogen 1), it would follow that helium were the heavier of the two constituents.

This conclusion is supported by the following considerations: It was long ago noticed by Lecoq de Boisbaudran and has since been confirmed, that in the spectra of elements which are chemically related the series of lines are shifted to the less refrangible side with increasing atomic weight. This is the case with Li, Na, K, Rb, Cs, with Cu, Ag, with Mg, Ca, Sr, with Zn, Cd, Hg, with Al, In, Fl. On the other hand it appears that in the order of their atomic weights in the same row of the periodic system, the series are shifted to the less refrangible side with increasing atomic weight; for instance, Na, Mg, Al; K, Ca; Cu, Zn; Rb, Sr; Ag, Cd, In. If we now assume that the atomic weights of the two constituents are between those of hydrogen and lithium, the supposition that helium is the heavier of the two constituents is in accordance with the fact that the three series of helium are shifted to the more refrangible side.

The hypothesis of the two constituents, thus far based upon a comparison of the line spectra of the elements, where "series" have been observed, is strengthened by the fact that it is possible

to make vacuum tubes which show the three series of helium much less brightly, while the three series of parhelium have suffered a much smaller decrease in intensity; so that the capillary tube looks green instead of yellow, the line 5016 surpassing D_3 in brightness. We first made this experiment by inserting a plug of asbestos in the tube connecting the gas supply with the vacuum tube. When the current of gas was cut off after a sufficiently short time the vacuum tube appeared green. We explained this by assuming that one of the constituents had more easily diffused through the plug, and was therefore the lighter one. However, this inference is open to objection. The green tubes were filled with a smaller amount of gas, hence the pressure in them was smaller than the pressure in the yellow tubes. The difference in the relative intensities of the two systems might also be due to the difference in pressure. This we found to be the case. We connected the vacuum tube with a vessel of about twenty-five times its volume. The vessel could be filled with mercury in the same way as the globe of a mercury pump. Thus we could alter the pressure in the vacuum tube without letting any gas escape, and in a small direct-vision spectroscope we saw the lines 4472, 4713, 5876, 7065 decrease in intensity relatively to 4922, 5016, 5048, 6678, 7282, when the pressure decreased, and increase again when the pressure increased. It is therefore not proved that the diffusion through the asbestos plug alters the relative amounts of the two constituents. The phenomenon of the green and yellow tubes may also be explained by the difference of pressure alone. The diffusion experiment ought to be repeated with larger quantities of the gas, and the question whether the amounts of the two constituents are altered could then be tested by weighing. But, however, this may turn out, the fact remains that the lines when grouped according to the variations of their relative intensities fall into the same two systems that have been established by the comparison of the spectrum with the spectra of other elements. The lines whose intensities we compared were those easily visible simultaneously in a small spectroscope, but as the principal series of helium is not represented

among them, it was thought necessary to compare the intensities of the two infra-red lines in the yellow and green tubes. Of these bolometric measurements an account is given at the end of this paper. The result was that while in the yellow tubes the helium line 11170 was on an average three times as strong as the parhelium line 20400, in the green tubes it was only 1.8 times as strong.

In the spectrum of the Sun's limb the stronger lines of the spectrum of clèveite gas had been observed and measured by Young long before this substance was discovered. To each line Young assigned a frequency number estimating the percentage of frequency with which the line was seen during six weeks of observation at Sherman in the summer of 1872. It is interesting to note that according to the frequency numbers the stronger lines fall into the two systems of helium and parhelium, the helium lines being always seen, the parhelium lines only about once in four cases. To the fainter helium lines the same remark does not apply, but we think it only likely that fainter lines may sometimes have been overlooked, though they were present.

Helium				Parhelium			
Runge and Paschen	Young	Frequency according to Young		Runge and Paschen	Young	Frequency according to Young	
4471.646	4471.8	100	25	4922.096	4922.3	30	8
4471.858							
4713.252	4713.4	2	2	5015.732	5015.8	30	10
4713.475							
5875.870	5875.98[1]	100	90	5047.816	5048.2	2	2
5876.209							
7065.48	7065.5	100	12	6678.37	6678.2	25	50
7066.00							

The case of 6678, which is far brighter than 7065 and 4472, and, nevertheless, has a much smaller frequency number, seems especially worthy of notice.

In the spectra of stars in which lines of helium and parhelium have been observed we could find no decided alteration

[1] Rowland's determination. The values are quoted from Frost's translation of Scheiner, *die Spectralanalyse der Gestirne.*

in the relative intensities, except in the case of Nova Aurigae.[1] Here the parhelium lines 5016 and 4922 are among the strongest lines of the spectrum, while 4472 is faint and D_3 was seen only by Huggins, and also appears to have been faint. 6678, which also belongs to parhelium, was observed by Huggins[2] and possibly also at the Lick Observatory, but none of the other helium lines have been seen.

In concluding, we may remark that we are well aware of the hypothetical nature of many of the arguments brought forward in this paper. Perhaps some time hence the theory of the oscillations that cause the series of lines may be discovered, and conclusions may then be drawn from them with certainty. We have not refrained from giving conclusions that rest on rather incomplete induction. But the attentive reader will have no difficulty in distinguishing fact from hypothesis.

ADDENDUM BY PROFESSOR F. PASCHEN.

The infra-red part of the spectrum could only be measured with instruments of the highest possible sensitiveness. I used the same spectroscopic bolometer employed in my former bolometric work. It consists of a bolometer and a prism of fluor-spar mounted on a spectroscope in which two concave mirrors have been substituted in place of the lenses of the collimator and telescope. The prism is automatically kept in the position of minimum deviation. The instrument has been standardized up to 9.429μ by means of a large concave grating.[3] This grating was made by Rowland especially for Langley's bolometric work and has comparatively few lines per millimeter. It was kindly lent by J. E. Keeler. The bolometer is double

[1] Many of the lines have been observed in the spectra of a large number of stars. See H. C. Vogel, *Sitz. d. K. Akad. d. W. Berlin*, 1895, p. 947; this JOURNAL, 2, 333.

[2] See a letter to *Nature* on the subject. *Nat.* Oct. 2, 1895.

[3] For the determination of the wave-lengths a new curve of dispersion for fluor-spar, more accurate than that used in my former work, has been employed. The wave-lengths near 2μ differ slightly from those given by the former curve of dispersion published in *Wiedemann's Annalen*.

like Langley's. Each strip has a length of 7^{mm}, a width of $0^{mm}.25$ (equal to that of the slit and the image of the slit in the spectrum), a thickness of $\frac{1}{2000}{}^{mm}$ and a resistance of 8 ohms. The strips are made from Lummer-Kurlbaum's platino-silver foil and blackened on the etched side with the soot of a flaring petroleum lamp, the other side remaining bright. The mean current in the bolometer was made 0.02 ampères. The galvanometer I used is described in the *Zeitschrift für Instrumentenkunde*, January, 1893. The astatic system of magnets is constructed for high sensitiveness, the magnets being from 1^{mm} to $1^{mm}.5$ long. The coils were so connected as to give a resistance of 15 ohms. I worked mostly at night. The galvanometer needle executed but one double swing, and when in circuit with the bolometer of 8 ohms resistance took about 17 seconds to come to rest. The scale stood at a distance of 2.5 meters. Under these circumstances the galvanometer gave a deflection of 1^{mm}, with a current of 8.3×10^{-12} ampères, that is 120000^{m} for one micro-ampère. The sensitiveness of the bolometer in connection with the galvanometer described may be defined by stating that a deflection of 1^{mm} corresponds to a difference of temperature of 84×10^{-7} degrees Centigrade.

When undisturbed by air currents, vibrations of the floor, or variations of temperature the mean of three deflections reached an accuracy of 0.2^{mm}.[1] As an example of medium excellence I give the following series of measurements:

OBSERVATIONS MADE JULY 14, 10 A.M.

Fine tube showing nothing but the lines of clèveite gas with great brilliancy. The tube was arranged end-on, and an image of the narrow part was thrown on the slit by means of a silvered mirror which lengthened the image by astigmatism. The induction coil[2] was worked by six accumulators.

[1] With some of the vacuum tubes this apparent accuracy was illusory, as induction currents seem to branch off through the bolometer in spite of careful insulation of the tube. This disturbance was principally felt with low pressure tubes.

[2] The one mentioned above as made and owned by Mr. E. Porter.

δ corr.	μ	Deflections Single	Mean	δ corr.	μ	Deflections Single	Mean
31° 31′.25	0.635	16.4	14.9	31° 3′.25	1.300	112.4	110.5
		13.4				108.5	
29 .25	0.656	29.5	29.8	1 .25	1.382	35.1	33.4
		30.0				31.7	
27 .25	0.680	48.7	51.9	30° 58′.25	1.512	11.1	9.0
		55.0				6.8	
25 .25	0.705	64.6	64.8	....	.....	.....	.....
		64.9					
23 .25	0.736	69.2	69.5	53 .25	1.730	27.8	25.6
		69.8				23.4	
21 .25	0.768	55.9	56.3	51 .25	1.814	27.4	30.3
		56.6				33.2	
19 .25	0.806	36.1*	36.9	49 .25	1.895	54.9*	52.3
		37.6				49.6	
17 .25	0.848	17.7	17.9			52.3	
		18.2		47 .25	1.979	68.5	69.2
15 .25	0.895	27.7	27.3			69.8	
		26.8		45 .25	2.060	76.7	77.1
13 .25	0.947	82.5	82.5			77.5	
		82.5		43 .25	2.140	69.8	69.3
11 .25	1.005	173.2*	178.4			68.8	
		183.5		41 .25	2.215	42.4	42.3
9 .25	1.070	238.8	235.9			42.2	
		233.0		39 .25	2.287	21.1*	20.5
7 .25	1.141	261.5	259.5			18.0	
		257.5				22.4	
5 .25	1.216	212.2	211.4	37 .25	2.362	8.0	8.3
		210.5				8.6	

The first column headed δ corr. gives the deviations of the arm carrying the bolometer. A correction is necessitated by the fact that the bolometric adjustment and the adjustment by eye do not exactly coincide. The column μ gives the corresponding wave-lengths. The third and fourth columns give the single deflections of the galvanometer and their mean. An asterisk signifies that the observation was disturbed. The curve of energy corresponding to these observations (Plate IV, Fig. 3), gave the following values for the places of three maxima:

	$\delta = 30^\circ\,45'.34$	$31^\circ\,7'.44$	$31^\circ\,23'.64$
wave-length =	$2^\mu.057$	$1^\mu.134$	$0^\mu.729$
intensity =	$77^{mm}.1$	$259^{mm}.5$	$69^{mm}.5$
proportional to:	1	3.37	0.901

Plate IV, Fig. 4 represents the spectrum of another vacuum tube provided with a window of fluor-spar, which also showed the

spectrum of clèveite gas with great brilliancy. From 10^{μ} to $2^{\mu}.5$ there is a continuous spectrum, the energy curve showing only the inevitable absorption bands of water vapor and carbon dioxide. The cause of this spectrum is the heat radiated from the inner walls of the capillary glass tube. The maximum of this continuous radiation lies at about $\delta = 28^{\circ}\ 50'$, which corresponds to a temperature of about 150°C., supposing the radiant body to be lampblack. Sometimes the capillary tubes became hot enough to singe the piece of paper with which they were held. At $2^{\mu}.5$ the continuous spectrum becomes inappreciable, and a new spectrum begins, consisting of the three maxima already mentioned above, which, according to this measurement, have the following positions:

	$\delta = 30^{\circ}\ 45'.94$	$31^{\circ}\ 7'.84$	$31^{\circ}\ 23'.40$
wave-length =	$2^{\mu}.035$	$1^{\mu}.119$	$0^{\mu}.734$
intensity =	$48^{mm}.7$	$129^{mm}.4$	$85^{mm}.3$
proportional to:	1	2.66	1.75

The last maximum is evidently the visible line 7282, to which light of the line 7065 is added on account of the small dispersion. As for the other two maxima, the formulæ of the two principal series give, when extrapolated, the values $2^{\mu}.04$ and $1^{\mu}.09$. The close coincidence of the maxima with these calculated values makes the identity appear very probable. A more stringent proof may be given by the following bolometric measurements. That the two lines belong to the spectrum of clèveite gas is proved by the fact that the height of the maxima increases and decreases with the brightness of the visible lines of clèveite gas. From Fig. 4 it may also be seen that there is no other maximum surpassing the energy of the heated glass, while, if a member of the first subordinate series of helium for $n = 2$ existed, its energy might be expected to surpass the energy of $2^{\mu}.04$, because 5876 surpasses 5016 in brightness. That one of the infra-red lines belongs to helium and the other to parhelium, is proved by the difference of their relative intensities in the yellow and green tubes. In the yellow tubes which show D_3 much brighter than 5016, the ratio of the intensities of the

PLATE IV.

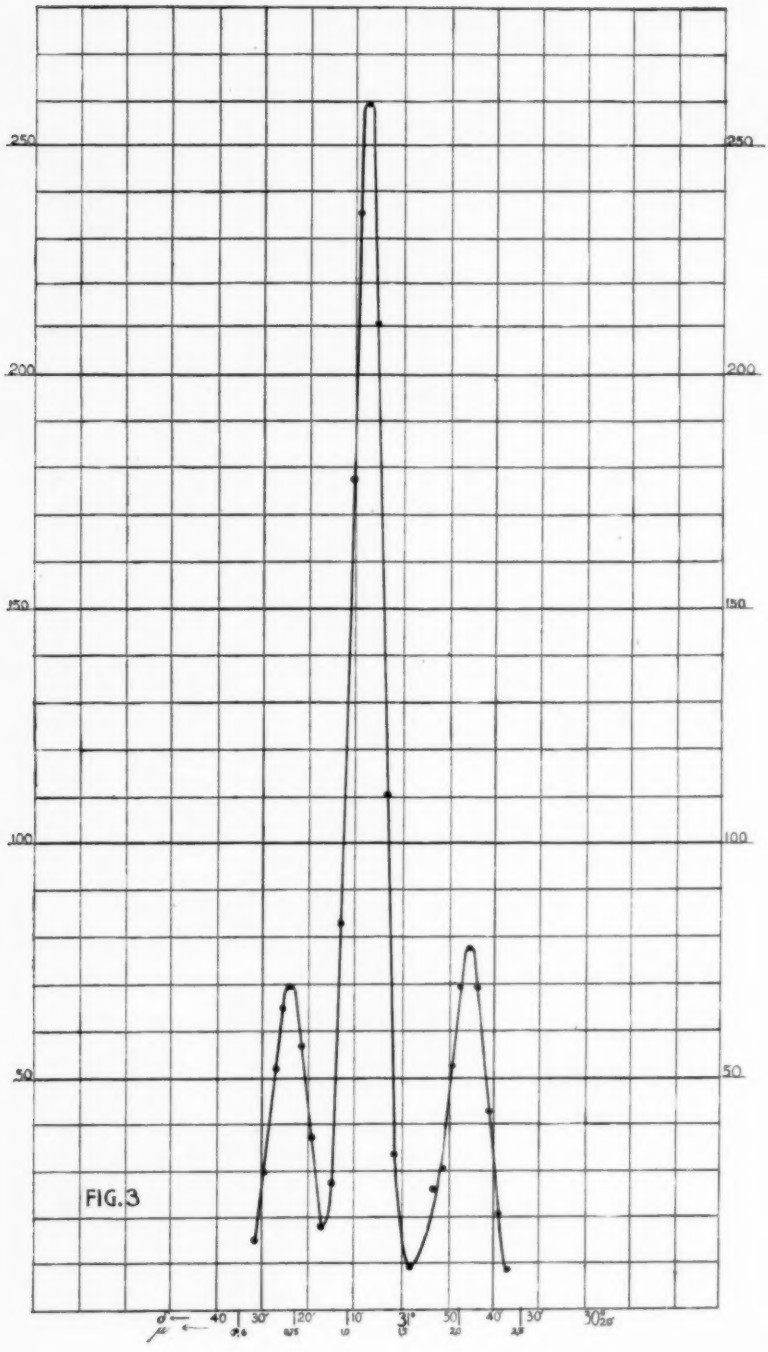
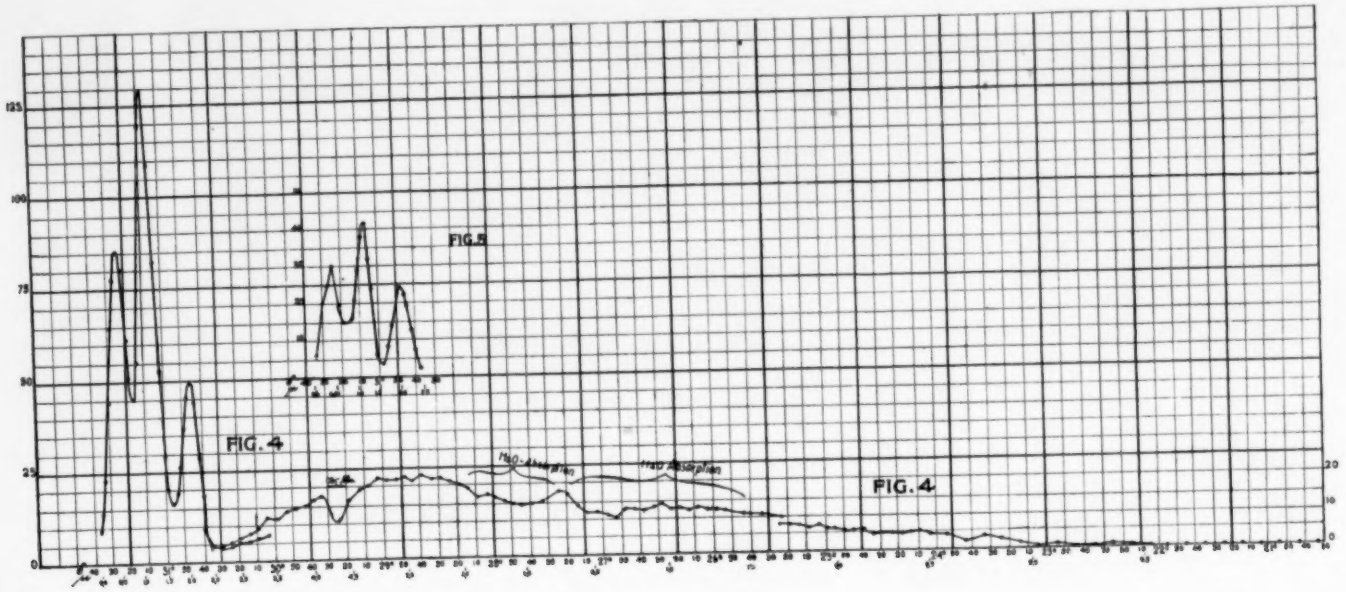


PLATE V.



Date, 1895	First Circle Reading	Maximum Height	Second Circle Reading	Maximum Height	Third Circle Reading	Maximum Height	Ratio of Heights	Remarks
		mm		mm		mm		
June 30	30°46′.34	20	31°9′.04	88.5	31°24′.24	25.1	1:4.43:1.26	Bright yellow tube closed with a quartz lens; showed no impurities. A second cylindrical lens collected the light on the slit.
July 1	46 .34	30.5	9 .74	101	24 .94	23	1:3.31:0.75	" " " " " " " "
" 2	44 .14	40.7	7 .14	140.7	.....	....	1:3.46	Same tube as before; silvered mirror instead of cylindrical quartz lens.
" 3	45 .54	38.6	7 .44	116.9	.....	....	1:3.03	Tube with window of fluor-spar; silvered mirror.
" 4	45 .99	41.3	7 .39	115.1	23 .44	68.9	1:2.79:1.67	" " " " " " " "
" 5	45 .94	48.7	7 .84	129.4	23 .40	85.3	1:2.66:1.75	" " " " " " " "
" 6	46 .64	42.7	7 .94	110.9	23 .64	80.0	1:2.60:1.87	" " " " " " " "
" 7	45 .84	43.2	7 .34	110.9	.....	....	1:2.57	" " " " " " " "
" 8(I)	47 .94	26.5	7 .64	59.0	26 .24	45.7	1:2.23:1.73	Current stronger than usual { Tube with quartz window, deteriorated; hydrogen lines strong, clèveite gas lines faint.
" 8(II)	47 .44	9.9	8 .24	20.5	(24.44?)	14.8	1:2.07:1.50	Current as usual, 6 accumulators { Tube with quartz window, deteriorated; hydrogen lines strong, clèveite gas lines faint.
" 10	45 .44	27.3	7 .44	76.0	23 .14	50.1	1:2.78:1.83	Yellow tube with quartz window. Hydrogen lines visible.
" 11(I)	45 .34	26.1	7 .84	69.4	23 .44	48.6	1:2.66:1.86	The same, with current reversed.
" 11(II)	45 .34	24.0	7 .84	63.64	23 .44	46.5	1:2.74:1.94	The same, current again as on July 10.
" 11(III)	45 .24	26.2	7 .84	72.5	22 .94	54.9	1:2.77:2.10	The same as July 11 (II), with 7 instead of 6 accumulators.
" 14(I)	45 .34	77.1	7 .44	259.5	23 .64	69.5	1:3.37:0.901	6 accumulators. Best golden yellow tube; no impurities visible in a small direct vision spectroscope. Quartz window in tube.
" 14(II)	45 .24	74.5	7 .97	236.5	23 .64	71.8	1:3.17:0.964	6 accumulators, current reversed. Best golden yellow tube; no impurities visible in a small direct vision spectroscope. Quartz window in tube.
" 14(III)	45 .34	32.1	7 .39	106.0	23 .44	29.7	1:3.30:0.925	Current as on July 14 (II); 3 accumulators. Best golden yellow tube; no impurities visible in a small direct vision spectroscope. Quartz window in tube.
" 15	47 .04	23.9	7 .79	41.8	23 .94	29.9	1:1.75:1.25	Tube with quartz window, recently filled through asbestos plug; green color (see description in the text); 5016 the brightest line in the visible spectrum. Hydrogen lines faint.
" 19	45 .34	53.5	7 .92	142.5	23 .34	55.3	1:2.66:1.03	Large tube with 2 glass windows, recently filled through asbestos plug. Gas supply cut off later than on July 15, so that the tube already looked yellowish. Hydrogen lines faint.
" 19	47 .04	8.0	8 .74	15.4	(20 .94?)	11.3	1:1.92:1.41	Small tube with quartz window, filled five days ago through asbestos plug; green color; showed 5016 about as bright as D_3. Hydrogen lines stronger. Measurement much disturbed and doubtful.
" 24(I)	44 .34	30.7	7 .49	113.7	23 .24	33.8	1:3.71:1.10	New golden yellow tube with quartz window. Hydrogen lines very faint.
" 24(II)	44 .89	45.0	7 .89	138.9	23 .44	49.4	1:3.09:1.10	The same, with current reversed.
Mean	30°45′.82		31°7′.88		31°23′.58			
m. e.	0′.204		0′.130		0′.191			

lines $2^{\mu}.04$ and $1^{\mu}.12$, varies between 1:2.2 and 1:4.4, and is generally 1:3.0. On the other hand, in the green tubes, in which 5016 equals 5876, or even surpasses it in brightness, the ratio was 1:1.75 or 1:1.92. The curve corresponding to a green tube is given in Plate V, Fig. 5. A comparison of the two lines in Fig. 3 or Fig. 4, with the same lines in Fig. 5, shows that in the green tubes the height of $1^{\mu}.12$ is about half its height in the yellow tubes, if $2^{\mu}.04$ is supposed to be of equal height in both. That $2^{\mu}.04$ is itself weakened in the green tubes is due to the pressure being so much lower than in the yellow tubes, which are so filled as to give maximum brightness. The above table contains the results of all the bolometric measurements of all the tubes examined. As quartz is sufficiently transparent for light down to $2^{\mu}.5$, the tubes provided with quartz windows could also be employed.

The means of the minimum circle readings and the means of the corresponding wave-lengths are:

δ	Mean Error of δ	Wave-length	Mean Error of Wave-length
30°45′.82	0′.204	$2^{\mu}.040$	0.0081
31 7 .88	0 .130	1 .117	0.0048
31 23 .74	0 .191	0 .728	0.0029

Why the relative intensities of the lines vary so considerably in the different yellow tubes and vary even in the same tube, when examined on different days, I am unable to explain, as vacuum tubes are difficult to control. Reversing the current also seems to produce a change, as may be seen from the table.

The two infra-red lines must also occur in the spectra of those stars in which the helium and parhelium lines have been observed. These stars must therefore radiate heat to us. That this has not been observed as yet may be due to the insufficient sensitiveness of the instruments employed.

K. Techn. Hochschule,
Hannover, November 24, 1895.

ON THE NEW GASES OBTAINED FROM URANINITE.[1]

By J. Norman Lockyer.

As Mr. Crookes has now published[2] the wave-lengths of the lines in the spectra of the new mineral gases observed by him in the tubes supplied by Professor Ramsay, I propose in the present paper to bring together some notes I have made (some of them some time ago) on the same subject.

The researches made at Kensington in connection with the new gases obtained from bröggerite and other minerals have consisted, to a large extent, of comparisons of the lines in their spectra with lines in the spectra of the Sun and stars. Preliminary accounts of these comparisons have already been given, and they show that the bright yellow line seen in the gas from bröggerite is by no means the only important one which appears.

Although the general distribution and intensities of the lines in the gases from bröggerite and clèveite sufficiently correspond with some of the chief "unknown lines" in the solar chromosphere and some of the stars to render identity probable, it was desirable to see how far the conclusion is sustained by detailed investigations of the wave-lengths of the various lines.

The Yellow Line, λ 5875.9.—Immediately on receiving from Professor Ramsay, on March 28, a small bulb of the gas obtained from clèveite, a provisional determination of wave-length was made by Mr. Fowler and myself, in the absence of the Sun, by micrometric comparisons with the D lines of sodium, the resulting wave-length being 5876.07 on Rowland's scale. It was at once apparent, therefore, that the gas line was not far removed from the chromospheric D_3, the wave-length of which is given by Rowland as 5875.98.

[1] Read before the Royal Society.

[2] *Chem. News*, August 23, 1895.

The bulb being too much blackened by sparking to give sufficient luminosity for further measurements, I set about preparing some of the gas for myself by heating brŏggerite *in vacuo*, in the manner I have already described. A new measurement was thus secured on March 30 with a spectroscope having a dense Jena glass prism of 60°; this gave the wave-length 5876.0.

On April 5, I attempted to make a direct comparison with the chromospheric line, but though the lines were shown to be excessively near to each other, the observations were not regarded as final.

Professor Ramsay having been kind enough to furnish me, on May 1, with a vacuum tube which showed the yellow line very brilliantly, a further comparison with the chromosphere was made on May 4. The observations were made by Mr. Fowler, in the third order spectrum of a grating having 14438 lines to the inch, and the observing telescope was fitted with a high power micrometer eyepiece; the dispersion was sufficient to easily show the difference of position of the D_3 line on the east and west limbs, due to the Sun's rotation. Observations of the chromosphere were therefore confined to the poles.

During the short time that the tube retained its great brilliancy, a faint line, a little less refrangible than the bright yellow one, and making a close double with it, was readily seen; but afterwards a sudden change took place, and the lines almost faded away. While the gas line was brilliant, it was found to be "the least trace more refrangible than D_3, about the thickness of the line itself, which was but narrow' (Observatory Notebook). The sudden diminution in the brightness of the lines made subsequent observations less certain, but the instrumental conditions being slightly varied, it was thought that the gas line was probably less refrangible than the D_3 line by about the same amount that the first observation showed it to be more refrangible. Giving the observations equal weight, the gas line would thus appear to be probably coincident with the middle of the chromospheric line, but if extra weight be given to the first observation, made under much more favorable conditions, the

gas line would be slightly more refrangible than the middle of the chromosphere line.

Pressure of other work did not permit the continuation of the comparisons. In the meantime, Runge and Paschen announced[1] that they also had seen the yellow line of the clèveite gas to be a close double, neither component having exactly the same wave-length as D_3, according to Rowland.

They give the wave-length of the brightest component as 5878.883, and the distance apart of the lines as 0.323.[2]

This independent confirmation of the duplicity of the gas line led me to carefully re-observe the D_3 line in the chromosphere for evidences of doubling. On June 14 observations were made by Mr. Shackleton and myself of the D_3 line in the 3d and 4th order spectra under favorable conditions; "the line was seen best in the 4th order, on an extension of the chromosphere or prominence on the northeast limb of the Sun. The D_3 line was seen very well, having every appearance of being double, with a faint component on the red side, dimming away gradually; the line of demarcation between the components was not well marked, but it was seen better in the prominence than anywhere else on the limb" (Observatory Note-book).

It became clear, then, that the middle of the chromosphere line, as ordinarily seen, and as taken in the comparison of May 4, does not represent the place of the brightest component of the double line, so that exact coincidence was not to be expected.

Though the observations are not yet quite completed, the circumstance that the line is double in both gas and chromosphere spectrum, in each the less refrangible component being the fainter, taken in conjunction with the direct comparisons which have been made, render it highly probable that one of the gases obtained from clèveite is identical with that which produces the D_3 line in the spectrum of the chromosphere.

Other observers have since succeeded in resolving the

[1] *Nat.* **52**, 128.

[2] See their corrected values in an article published in this number of the ASTROPHYSICAL JOURNAL (Ed.).

chromospheric line. On June 20, Professor Hale found the line to be clearly double in the spectrum of a prominence, the less refrangible component being the fainter, and the distance apart of the lines being measured as 0.357 tenth-meters.[1]

The doubling was noted with much less distinctness in the spectrum of the chromosphere itself on June 24. Professor Hale points out that Rowland's value of the wave-length (as well as that of 5875.924, determined by himself on June 19 and 20) does not take account of the fact that the line is a close double.

Dr. Huggins, after some failures, observed the D_3 line to be double on July 10;[2] he also notes that the less refrangible component was the fainter, and that the distance apart of the lines was about the same as that of the lines in the gas from clèveite, according to Runge and Paschen.

It may be added, that in addition to appearing in the chromosphere, the D_3 line has been observed as a bright line in nebulæ by Dr. Copeland, Professor Keeler, and others; in β Lyræ and other bright line stars; and as a dark line in such stars as Bellatrix, by Mr. Fowler, Professor Campbell, and Professor Keeler. In all these cases it is associated with other lines, which, as I shall show presently, are associated with it in the spectra of the new gases.

The Blue Line, λ 4471.8.—A provisional determination on April 2, of the wave-length of a bright blue line, seen in the spectrum of the gases obtained from a specimen of clèveite, showed that it approximated very closely to a chromospheric line, the frequency of which is stated as 100 by Young.

This line was also seen very brilliantly in the tube supplied to me by Professor Ramsay on May 1, and on May 6 it was compared directly with the chromosphere line by Mr. Fowler. The second order grating spectrum was employed. The observations in this region were not so easy as in the case of D_3, but with the dispersion employed, the gas line was found to be coincident with the chromospheric one. In this case also, the

[1] *A. N.* 3302. [2] *A. N.* 3302.

chromosphere was observed at the Sun's poles, in order to eliminate the effects due to the Sun's rotation.

In a former note,[1] I have pointed out that this line does not appear in the spectra of the gases obtained from all minerals which give the yellow line.

Besides appearing in the spectrum of the chromosphere, the line in question is one of the first importance in the spectra of nebulæ, bright line stars, and of the white stars such as Bellatrix and Rigel.

The Infra-red Line, λ 7065.5.—In addition to D_3 and the line at 4471.8, there is a chromospheric line in the infra-red which also has a frequency of 100, according to Young. On May 28, I communicated a note to the Royal Society stating that this line had been observed in the spectrum of the gases obtained from bröggerite and euxenite,[2] solar comparisons having convinced me that the wave-length of the gas line corresponded with that given by Young; and I added "it follows, therefore, that besides the hydrogen lines, all three chromospheric lines in Young's list which have a frequency of 100 have now been recorded in the spectra of the new gas or gases obtained from minerals by the distillation method."

M. Deslandres, of the Paris Observatory, has also observed the line at 7065 in the gas obtained from clèveite.[3]

Other Lines.—Determinations of the wave-lengths of many other lines in the spectra of the new gases have been made, chiefly with the aid of a Steinheil spectroscope having four prisms, and the results leave little doubt as to the coincidence of several lines with those appearing in the chromosphere, nebulæ, and white stars.

It seems very probable, also, that many lines which have been noted, and for which no origins have yet been traced, belong to gases which have not hitherto been recorded in the chromosphere.

[1] *Proc. R. Soc.* **58**, 114.

[2] *Proc. R. Soc.* **58**, 192.

[3] *C. R.* June 17, p. 1331, 1895.

The following table summarizes the chief lines which have so far been recorded in the new gases from various minerals, some of which show D_3 while others do not. Only those lines which also appear in the spectrum of the chromosphere, nebulæ, or Orion stars, are given in the first instance. There are other lines which are probably also associated with chromospheric ones, but further investigation of them is considered desirable before they are included in the list.

The first column of the table gives the wave-lengths of the lines on Rowland's scale, while the second gives the wave-lengths on Ångström's scale; the third gives the frequency of the lines in the chromosphere according to Young. In the fourth column lines photographed with the prismatic camera during the total eclipse of April 16, 1893, are shown; these have been included because in some cases lines which appear to be comparatively unimportant in Young's list were photographed as important lines. The fifth column indicates probable coincidences with lines in the spectrum of the Orion nebula; the accuracy of these wave-lengths is of necessity less than in the case of the chromosphere; with the exception of D_3 they are taken from my paper on the photographic spectrum of the Orion nebula.[1] The sixth column shows probable coincidences with dark lines in the spectrum of Bellatrix, this being taken as an example of the Orion stars;[2] the lines 4922.3 and 5015.8 have been photographed since the date of the paper to which reference is made.

The last column gives the wave-lengths, from Mr. Crookes' table, of the lines observed by both of us.

[1] *Phil. Trans.* 186A, 76, 1895.

[2] *Phil. Trans.* 184A, 695, 1893.

Wave-length (Rowland)	Wave-length (Ångström)	Chromosphere (Young)	Eclipse 1893. Max. intens. = 10	Orion nebula. Max. intens. = 6	Bellatrix. Max. intens. = 6	Crookes' measures
		Frequency	λR	λR	λR	λR
3888.7	3888.0	—	probable*	..	probable	3888.5
3964.0	3963.5	—	3963.8	..	3964.0(3)	3964.8
4026.5	4025.9	†	4026.0(6)	4026(3)	4026.0(6)	4026.1
4389.5	4388.5	1	4390.0(1)	4390(2)	4389.0(5)	4386.3
4471.8	4471.2	100	4471.8(10)	4472(4)	4472.0(6)	4471.5
4713.4	4712.5	2	4713.2(5)	4716(2)	4715.0(3)	4713.4
4922.3	4921.3	30	4922.0(4)	4924(3)	4922.0(2)	4922.6
5015.8	5015.0	30	5016.0(4)	..	5016.0(1)	5015.9
5048.2	5047.8	2	..	..	..	5047.1
5404.1	5403.1	5				
5429.9	5428.8	8				
5875.9	5874.9	100	5876.0	5876.0	5876.0	5876.0
5991.6	5990.0	15				
6065.7	6064.5	5				
6122.43	6121.43	5				
6141.9	6140.6	15				
6347.3	6346.2	10				
6371.6	6370.5	5				
6678.3	6676.9	25	..	..	..	6678.1
7065.5	7064.0	100	..	..	..	7065.5

† Professor Young has recently called attention to the fact that although this line was not included in his chromospheric list, he observed and published it in 1883; its frequency is about 15. (*Nat.* **52**, 458.)

* This line is too close to a hydrogen line to enable a definite statement to be made.

OUTLINE OF AN ELECTRICAL THEORY OF COMETS' TAILS.

By Reginald A. Fessenden.

In a recent paper by J. J. Thomson, reviewed in the November number of this Journal, it is shown that carbon and hydrogen give different spectra according to whether they are positively or negatively electrified.

These results are at least suggestive when considered in connection with that phenomenon which we call a comet's tail. For, from the experiments of Hallwachs, Righi, Lenard and Wolf, and Elster and Geitel, we know that if an uncharged body be exposed to ultra-violet light the surface disintegrates, the particles produced fly off, carrying charges of negative electricity, and the body thus becomes positively charged though neutral before. Since the spectrum of the Sun is very rich in ultra-violet rays, we may state with some certainty that negatively charged particles are emitted from that side of a comet which faces the Sun, and that the comet's nucleus has a positive charge.

It has been observed that in the Sun's chromosphere the red line of hydrogen is brighter than the green, indicating according to J. J. Thomson's results, that the hydrogen in the Sun is negatively electrified.

The negatively electrified particles emitted from the comet's nucleus must therefore move under the influence of four forces: a force G due to gravitation, and acting toward the Sun; a force P due to the electrostatic repulsion of the negative charge on the Sun; a force Q due to the attraction of the positive charge on the comet's nucleus; and a force R due to the electrostatic repulsion of each negatively electrified particle for all the other similarly electrified particles.

Since observation shows that the shape of the tail (aside from certain irregularities revealed by photographs, which I have

dealt with in another portion of this note), is such as would be produced by such forces, since, moreover, the tail gives the candle spectrum of carbon, and must, therefore, according to Thomson's results, consist of negatively electrified carbon particles, a certain degree of probability attaches to the theory which I venture to put forward:—that a comet's tail consists of negatively charged particles driven off from the nucleus by the action of the ultra-violet light of the Sun, and that its shape is the resultant effect of the four forces above mentioned.

The theory that the tail is due to an electrical effect is of course not new, having been suggested at an early date, and elaborated by Zöllner and by others. Their theories, however, are not definite, or postulate an electrical action proportional to the volume of the matter forming the tail, and two of the forces are omitted. Thomson's results, however, taken in conjunction with those of the above mentioned observers who have experimented upon the action of ultra-violet light, enable us, for the first time, to put forward the hypothesis with a certain degree of probability.

To produce the effects observed, the potential of the Sun need not be very high. According to Bredichin the repulsive force acting on a tail showing the candle spectrum is from $\frac{1}{10}$ to $\frac{1}{7}$ that acting on a tail which he supposes to consist of hydrogen. He did not, however, take into account the force Q due to the positive charge on the nucleus, and as this would be a comparatively larger component of the total force acting on the lighter tail, his results are too small. Unless therefore, we are prepared to postulate the existence of some substance lighter than hydrogen, we must suppose that each atom of carbon forming the heavier tail has one ionic charge on it, or acts as if it were monatomic. This is probable on other grounds. Therefore the total quantity of electricity on the atoms of one gram of carbon will be nearly 8000 coulombs.

If the comet is at a distance from the Sun equal to the radius of the Earth's orbit, the gravitational force per gram of matter will be approximately 0.57 dynes. From the mean of Bredichin's

results for the carbon tail we have, electrical repulsion = 1.5 times gravitational attraction. Therefore if q be the quantity, in electrostatic units, of electricity on the Sun, we have (the specific inductive capacity of a vacuum being nearly unity),

$$.57 \times 1.5 = \frac{q \times 800 \times 3 \times 10^9}{(93000000 \times 160933)^2}.$$

Dividing the value of q so obtained by 14×10^{11} (the diameter of the Sun in centimeters, and therefore its electrostatic capacity), we get for the potential of the Sun 50 electrostatic units, roughly, or about 15000 volts. This figure is by no means improbably high; in fact, it is low compared with the differences of potential observable in our own atmosphere.

Some consequences of this theory may be worthy of mention. These are :

So long as the matter forming the tail is being given off, the positive charge on the nucleus is increasing. The resultant force acting on a particle of the tail, just after it has been emitted, will therefore finally become directed back again to the nucleus and the tail will form no longer. But if in this condition the nucleus approach the Sun, the forces G and P will increase, the force Q remaining constant. Therefore the resultant will change direction, and the tail will form once more, and become larger the nearer the comet approaches the Sun. This agrees with observation.

After a time, when the potential on the nucleus has increased to a certain amount, and the comet is at a certain distance from the Sun, the effect of the nucleus charge will preponderate, and the particles shot out will return to the nucleus. This appears to have been observed in the case of Coggia's comet.

The head of the comet must become smaller as it approaches the Sun, as the electrostatic repulsion P will then preponderate and cause the curvature of the first portion of the path of the particles to be much greater.

Owing to the great extremes of heat and cold to which the nucleus must be subjected, portions probably split off from time to time. Every such splitting must be marked by a sudden

increase in the size of the tail, for if a spherical nucleus splits up into eight spherical portions each of half the radius of the original, the capacity will be quadrupled, and the total quantity being the same as before, the Q force will be less. This may account for the irregularities which have been observed in some tails, each irregularity corresponding to the splitting off of a fragment from the nucleus.

On the splitting up of a nucleus, new tails may be developed, for fresh surfaces will be exposed to the ultra-violet light, and elements which had been entirely driven off from the outside surface can now be acted upon. If the different parts of the nucleus clash against one another, we might expect to get the CO spectrum under such conditions.

If, however, a nucleus splits up, the chances are against the pieces remaining together. For example, if a 2 kilogram carbon nucleus splits up into two equal pieces, the gravitational attraction between the two will be $\frac{0.0665}{d^2}$ dynes, d being the distance between the two. But if each possesses a charge of 0.26 electrostatic units of electricity, the electrostatic repulsion would balance the gravitational attraction. Since the total quantity, as given above, on the atoms of one gram of carbon is 24×10^{12}, if the original nucleus had shed more than 10^{-14} grams of carbon as a tail, the two portions would be repelled from each other, and would gradually separate. This was observed in the case of Biela's comet, and generally it is probable that a nucleus which consists of more than one piece cannot hold together unless the fragments are very large.

Since the positive charge on the nucleus is continually increasing, the attraction between it and the Sun will be greater than that of gravitation, and continually increasing. This will have a similar effect to that produced by a resisting medium, *i.e.*, the period of the comet will be shortened. From the figures given above it will be seen that if a comet weighing one kilogram has used up one milligram in forming a tail, the resultant force in the direction of the Sun will be 1.0000015 times that due to gravita-

tion alone. This retardation seems to have been observed in the case of Encke's comet.

On this theory a very remarkable effect should follow, in certain cases, the splitting up of a nucleus into two parts, but I should hesitate to mention it, had it not been observed in the case of Biela's comet. If a nucleus split up into two parts, A and B, A being the larger, then at first B will be the brighter. But the positive charge on A will attract the negatively charged particles of B's tail, and if the other forces have the right magnitudes a portion of the tail will shoot out to A and neutralize a portion of its charge. Thereupon A will flash out brighter, until after a time, owing to A having its charge partly neutralized as fast as it forms, while the charge on B is steadily accumulating, B will become the more heavily charged and now a portion of A's tail will shoot out to B, and the whole process will be reversed, to be repeated again and again as long as the conditions are favorable. Should this hypothesis prove true, a new importance attaches to the subject. For we may regard a comet as a gigantic electroscope, giving us the absolute electrostatic potential of the Sun, and possibly, by more refined observations, that of other heavenly bodies.

The presence of negatively charged hydrogen in the chromosphere cannot be considered as absolute proof that the Sun is negatively electrified as a whole, as the other ends of the lines of force may end on the Sun. The subject is one which the writer is unable to discuss. A number of theories might be advanced, but at present our knowledge on the subject is too small to render their consideration profitable.

WESTERN UNIVERSITY OF PENNSYLVANIA,
Allegheny, Nov. 30, 1895.

PHOTOGRAPHIC AND VISUAL OBSERVATIONS OF HOLMES' COMET.

By E. E. Barnard.

This object was discovered by Mr. Edwin Holmes in London, on November 6, 1892, while endeavoring to find the Great Nebula of Andromeda with a reflecting telescope.

From several points of view it was one of the most remarkable comets ever observed.

At the time of discovery it was distinctly visible to the naked eye as a slightly ill defined star of the 6th magnitude. The remarkable fact that the comet had attained naked eye visibility when discovered, coupled with the further fact that this region must have been repeatedly swept over by comet seekers to within a few days of the discovery, shows that the comet must have rather suddenly attained its conspicuous visibility.

When found by Mr. Holmes this object was already some five months past perihelion (T = June 13, 1892) and had been theoretically for several months in a far better condition for discovery.

From the care and skill shown by the large number of astronomers now engaged in comet seeking, there can be no doubt whatever but that this comet did not exist during that time with anything like one-tenth of the brightness it had at discovery.

From this, and its subsequent remarkable behavior, several astronomers argued that the object was not a comet in the true sense of the word, and that it must be the product of some celestial accident. This idea was further strengthened when its orbit was computed, and was found to lie within the asteroid zone. This orbit differed altogether from that of the ordinary comet by being almost circular.

According to the orbit the comet ought to have been easily visible at every previous opposition and should have been discovered long ago.

It seemed highly probable at least that it should be seen at its next opposition when it would be very favorably placed for observing. Though carefully searched for, no trace of the comet could be seen. The writer made a careful search for it both with the 12-inch and the 36-inch of the Lick Observatory, but without any success whatever.

From the fact that the orbit lay out among the asteroids Mr. Corrigan of Saint Paul and Dr. Daniel Kirkwood suggested that possibly two asteroids had collided and produced the phenomenon of a comet. However much faith may be placed in this hypothesis, I think, from the peculiar phenomena witnessed during the visibility of the comet, that it does not now exist in the cometary form, and furthermore, I do not think that it will ever be seen again, though it should return to perihelion in 1899. All the circumstances connected with it rather tend to show that it was of only a temporary nature.

The announcement of the discovery of this comet was received at the Lick Observatory on November 8, 1892, and it was observed that night with the 12-inch refractor. Its appearance was absolutely different from that of any comet I had ever seen. It was a perfectly circular and clean cut disk of dense light, almost planetary in outline. There was a faint, hazy nucleus with a slight condensation some 5″ south following the nucleus. With the naked eye the comet was just as bright, exactly, as the brightest part of the Great Nebula of Andromeda, near which it was visible.

At $8^h\ 0^m$ a careful estimate of its diameter made it 260″. At $9^h\ 40^m$ careful micrometer measures made the north and south diameter 286″.

On November 9, at $6^h\ 5^m$ the comet was brighter to the naked eye than the brightest part of the Andromeda nebula. At $6^h\ 20^m$ the measured diameter was 337″ north and south, with the 12-inch telescope; there was a faint diffused glow 12′ in diameter surrounding the comet symmetrically and a short, faint diffusion south following. The nucleus preceded the center about ½′ while at the center there was a slight condensation. With the naked eye at $8^h\ 0^m$ the comet looked like a small star and

almost equal in brightness to ν Andromeda, and could not be distinguished from a star. At $8^h\ 30^m$ it was looked at with the 4-inch comet seeker—the diffused haze could be seen surrounding it with faint traces of a tail.

On November 11 it was observed with the 36-inch. The nucleus was found to be almost stellar and faint. A small star 20″ from the nucleus was shining through the comet. At $11^h\ 0^m$ it was observed and measured with the 12-inch; north and south diameter = 397″.

November 12. To the naked eye it was certainly less bright.

November 13. At $9^h\ 0^m$ the comet was certainly less bright and fading. At $11^h\ 45^m$, with the 12-inch the measured north and south diameter was 582″. It was less bright and not so definite.

November 14. With the 12-inch the comet was larger and fainter and more diffused. It was also fainter to the naked eye.

November 16. With the 12-inch the north and south diameter was about 10′. It was less dense looking, large and diffused and much fainter. At this observation there was nothing different in its appearance from the ordinary comet, except its size. There was an ill defined nucleus preceding the center and diffused brightening south following the nucleus. With a low power the comet was still fairly well defined. Several small stars could be seen shining through it. To the naked eye it was still stellar but fainter.

November 21. The comet was about 21′ in diameter and very diffused with a feeble brightening near the middle. To the naked eye it appeared much fainter than the Andromeda nebula.

November 24. At 8^h it was very large and diffused—at least 20′ in diameter.

December 5. The comet was not seen with the naked eye. In the 12-inch, by rapid sweeping with a low power, it appeared to be larger than the field of view (42′)—very large and vague.

January 4, 1893. It was excessively faint and large—indefinitely large; with a power of 150 on the 12-inch there was only the most excessively faint trace of the comet—a feeble glow extremely difficult to see.

January 16. Bad weather interfered with observations until January 16, when it cleared at dark. It seemed scarcely possible that the comet could be seen again, but from the importance of any positions of it, I thought it worth trying once more. The 12-inch was set for it, and upon looking in the telescope I was surprised to see a small, bright, hazy star. Thinking some mistake had been made, the telescope was again set only to find the same object. It seemed impossible that this star-like object could be the excessively faint and diffused nebulosity previously seen. Observations for motion, however, soon showed that it was in reality the comet.

Micrometer measures at $8^h\ 15^m$ made the diameter 29″. It was of about the 8th magnitude and strongly condensed. In the finder, however, it appeared perfectly stellar and could not possibly be distinguished from an 8th magnitude star.

At $9^h\ 50^m$ the mean of two measures gave 32″.4 for the diameter. At this time there had begun to appear in the condensation a small nucleus which had not been visible at first. It seemed to brighten rapidly while being watched, and soon became very distinct. At $10^h\ 20^m$ there was no question but that the nucleus was brightening; it seemed to form and become clear and distinct right before one's eyes.

At $10^h\ 30^m$ the 36-inch was turned upon the comet. It appeared very beautiful and remarkable in the great telescope. With this instrument its diameter was measured. The definiteness of the object may be inferred from the consistency of the measures.

$10^h\ 29^m$	diameter =	43″.4
10 30	"	44 .9
10 31	"	43 .6

In the great telescope it looked exactly as it did on November 8 when first seen with the 12-inch. It was pretty well terminated and had a pretty bright nucleus. A few minutes later another set of measures was made of its diameter.

$10^h\ 42^m$	diameter =	47″.8
	"	47 .9
10 45	"	46 .0

The nebulosity was bluish, but the nucleus was hazy and yellowish and central. At $10^h\ 55^m$ there was a feeble glow about the comet, something like 1′ in diameter. Further measures were made with the great telescope.

$11^h\ 13^m$ diameter $= 47''.3$
11 15 " 46 .1

On this night there was no question whatever but that the nucleus actually formed in a few hours' time, while the comet was under observation; at the same time the body of the comet appeared to be expanding gradually.

January 17. At this date at $6^h\ 20^m$ the comet had a beautiful star-like nucleus. The nebulosity of the head surrounded it symmetrically, but was not bright. The diameter of this nebulosity was measured at $7^h\ 16^m$ and was found to be 46″, but because of its lesser brightness, the measures were not so certain. At 8^h the nucleus was very conspicuous—the nebulosity being very subordinate to it, the coma being merely a bright glow about the nucleus. The nucleus itself was yellowish and not perfectly stellar. At $8^h\ 20^m$ the comet and nucleus appeared like a star shining through fog. The nebulosity faded away softly from the nucleus which shone out conspicuously from it.

January 18. At $7^h\ 0^m$ the measured diameter was 89″ with the 12-inch. At $7^h\ 45^m$ the nucleus was difficult to see and was not brighter than the 13th magnitude.

January 19. With the 36-inch at $6^h\ 48^m$ the north and south diameter was roughly measured and $= 121''$. The nucleus was bright and there was no definite limit to the nebulosity.

January 20. With the 36-inch at $6^h\ 45^m$ the measured diameter was 136″. The nucleus was of the 10th magnitude and quite conspicuous, while the comet was much brighter in the middle. Taken altogether the object looked like a spherical mass of vapor, rounding up beautifully, with the nucleus shining in the middle.

January 22. With the 36-inch the comet was very diffused and was estimated to be 3′ or 3′.5 in diameter. At $7^h\ 30^m$ the nucleus was very indistinct and about 12th magnitude. There was a hazy glow close about the nucleus that seemed to partially hide it.

January 24. On the moonlit sky, the comet, in the 12-inch, appeared to be about 1′ in diameter — its greater portion being lost in the brightness of the sky. There was no nucleus. With the finder the comet appeared rather bright and cometary — like a large and conspicuous nebula.

After this, absence from the Observatory prevented the comet from being followed further.

These notes are condensed from those made at the times of observation, and show the remarkable transformations this object underwent. They may be useful sometime in aiding us to understand the nature of this remarkable body.

Photographs of the comet were made with the Willard portrait lens; the most interesting and important of these was the one made on November 10. An enlargement of this picture is herewith presented (Frontispiece).

So far as I can learn, this seems to have been the only photograph made of the comet in the first stages of its visibility.

The picture shows the well-defined outline of the comet and it also shows the faint diffused nebulosity seen surrounding it in the telescope.

There is one other thing that this photograph shows (and which seems to have been generally overlooked) that must sometime be of the highest importance in the solution of the mystery surrounding this extraordinary object. To the southeast of the comet, distant about one degree or so, is shown a large irregular mass of nebulosity covering an area of one square degree or more, and noticeably connected with the comet by a short hazy tail. Evidences of this diffused nebulosity had been seen when examining the region about the comet with a low power on the 12-inch. This very extraordinary appendage deserves the earnest attention of those who are at all interested in this comet.

KENWOOD OBSERVATORY,
December 14, 1895.

NOTE.—I find in examining the reproduction of this photograph, that the central, well-defined body of the comet has been lost in the half-tone, the outline shown being that of the diffused haze surrounding the comet proper. The nebulous appendage, however, is fairly well shown. E. E. B.

THE MODERN SPECTROSCOPE. XV.

By F. L. O. WADSWORTH.

IN the last number of the ASTROPHYSICAL JOURNAL I described a number of forms of "fixed arm" concave grating mountings which were designed with special reference for use as astronomical spectroscopes or in radiometric and interferential work for which the ordinary form of mounting is unsuitable. In calling attention to the great advantages which the concave grating possessed for astronomical spectroscopy[1] I pointed out that not the least important of these was its astigmatism, by virtue of which star spectra were broadened out into bands of a sensible width, making the use of a cylindric lens unnecessary in visual observation, and eliminating the danger of mistaking a defect in the film for a spectral line in a photographic record.

Valuable, however, as this property of astigmatism is in the case of stellar spectra, there is another class of astrophysical work in which it is most decidedly disadvantageous, and would indeed preclude the use of the instrument entirely if it could not be gotten rid of or overcome in some way. Reference is made not only to the direct visual comparison of spectra from different sources which is frequently desirable in identifying the lines in celestial spectra, but to two other quite as impor-

[1] At that time I did not know that the concave grating had ever actually been used on an astronomical telescope, but I have since found that it was used by Professor Crew (for the first time, I believe) on the Lick telescope in 1892. The mounting used by Professor Crew was the usual Rowland form, whose use was easily possible in this case because of the very short radius of curvature (only 22 inches) of the grating. Professor Crew points out clearly, not only the advantages referred to in my paper, but some others of almost equal importance, and speaks enthusiastically of the possibilities of the instrument in astronomical research. As he says at the close of his article: "The astronomical world is only just beginning to realize its indebtedness to Rowland for this instrument at once so beautiful and so powerful." See paper on "The Use of the Concave Grating for the Study of Stellar Spectra," by H. CREW. *A. ana A.* **12**, 166, Feb., 1893.

tant problems: (1) the comparison, either visually or photographically, of the spectra from adjacent portions of the surface of the Sun or of the planets, for the purpose of determining the nature and extent of the reversals of lines in the Sun-spots, faculæ or prominences, or the displacements of the lines due to varying velocities of different portions of the surface in the line of sight; and (2) the formation and observation of monochromatic images of the whole or part of the surface for the purpose of determining, for example, the form of the prominences, either visually, through a wide slit tangent to the limb of the Sun, or photographically through the narrow moving slit of the spectroheliograph. For all of these purposes the concave grating offers the same advantages in the way of simplicity, accuracy and efficiency in light gathering power that it offers in other classes of work, but its astigmatism when used and mounted in the ordinary manner renders its employment in that way impossible.

In a paper published in *Astronomy and Astro-Physics* for November, 1894, Dr. Sirks[1] pointed out, for the first time, I believe, that in the first problem mentioned above, that of a direct comparison between two spectra from different sources, the effect of astigmatism may be avoided by placing the comparison prism which introduces the lateral beam, not against the slit of the spectroscope, but at a distance d from it which, in the case of the Rowland mounting, is equal to $\frac{\rho}{\cos i} - \rho \cos i = \rho \sin i \tan i$. Under these circumstances the spectral images have sharply defined edges corresponding to the edges of the prism, and may, therefore, be easily brought into coincidence. The same result may be secured by placing both of the sources, one just above the other, at the point indicated, or, better, since it would in general be inconvenient to then bring them into exact coincidence, by placing one of the sources at this point, and then forming the image of the other at the same point by means of a lens

[1] "On the Astigmatism of Rowland's Concave Gratings." *A. and A.* 13, 763, Nov., 1894.

PLATE VI.

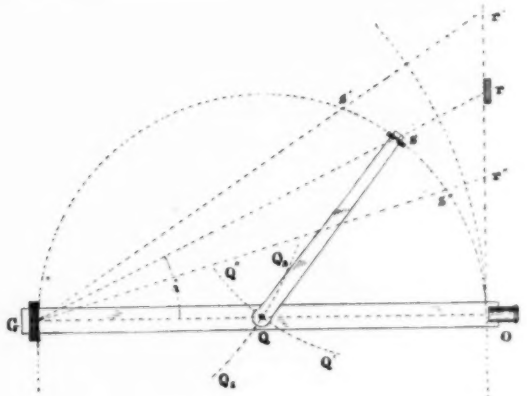


Fig. 1

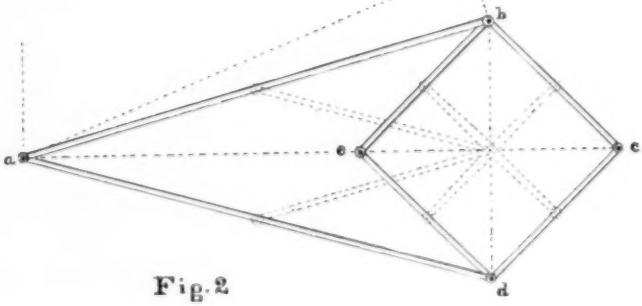


Fig. 2

Fig. 3

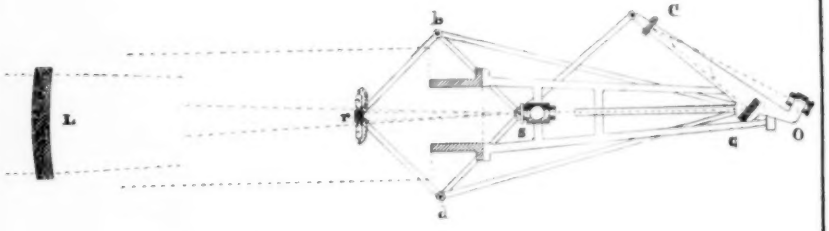


Fig. 4

or mirror. Then by adjusting the position of the image with reference to the first source the spectra may either be brought into coincidence or separated or made to overlap to any required degree.[1]

Although Dr. Sirks pointed out clearly the analytical conditions to be fulfilled for avoiding the effects of astigmatism, he suggested no form of mounting by which these conditions could be practically realized in the actual use of the grating. His method is manifestly impracticable, to say the least, if we are compelled to reset the source or the comparison prism by trial or measurement for every movement of the grating. The only alternative which presents itself is to fix this part of the system and move the whole grating mounting with respect to it, a method of procedure which it is practically impossible to adopt with the customary Rowland mounting, except, perhaps, for the very smallest sizes of instrument. But if we use a form similar to that shown in Figs. 12 and 13, Plate XVI. of the December number of this journal, the problem becomes less difficult, and is in fact susceptible of a very simple and satisfactory solution by means of a pure link work combination. Let G, Fig. 1, Plate VI., be the position of the grating, s the slit, r the source or the reflecting prism, and O the observing eyepiece placed normal to the grating and at a fixed distance, ρ, from it as in Rowland's mounting. Then in order to satisfy the conditions of a non-astigmatic mounting, the slit must lie always on the circumference of the circle $O\,s''\,s\,s'$ of radius $\frac{\rho}{2}$, while the source r lies at the intersection of Gs produced with the line $O\,r$, tangent at O to the circle of radius $G\,O = \rho$. For then

$$Gs = 2\,G\,Q \cos i = \rho \cos i$$

$$\text{and } Gr = \frac{\rho}{\cos i'}, \text{ or } d = G\,r - s\,r = \frac{\rho}{\cos i'} - \rho \cos i.$$

[1] It is of interest to note in this connection that when a condensing lens is used in front of the grating there is always one position of the grating in which dust particles, striæ, etc., on the surface of the lens will be in focus in the spectrum; a phenomena sometimes observed when the lens is dirty.

To satisfy the first condition it is simply necessary to mount the slit on the end of an arm of length $\frac{\rho}{2}$ pivoted at Q. To satisfy the second we must have from the geometry of the circle $Gs \times Gr = GO^2 = \rho^2 = \text{Const.}$ As is well known, this condition is satisfied by any inversor linkage[1] of which the two most simple forms are Hart's inversor and Peaucellier's cell, of which the last is shown in Fig. 2. This is the most suitable for the present purpose on account of its compactness and symmetry. In it we have $ae \times ac = ab^2 - be^2$, which to satisfy the above condition must equal ρ^2.

Hence, if we place the source or comparison prism at the vertex c of this cell and pivot the other two vertices e and a to the ends s and G of the links Qs, QG, respectively, the desired geometrical conditions will always be fulfilled and we obtain the simple and symmetrical mounting shown in Fig. 3. We may then fix either the pivot at G, the pivot at s, or the pivot at r in position. If G is fixed, Q may also be fixed, in which case the eyepiece O also remains fixed, but the slit and comparison prism r slide along the line Gsr, while this line itself rotates about the pivot G. A simpler arrangement therefore is obtained by fixing either the pivot s or the pivot r, leaving Q free. Then the grating and comparison prism, or the grating and slit, slide along the bar Gsr, which remains fixed, and the point Q describes a curve $Q'QQ''$ (if s is fixed), or QQ_1Q_2 (if r is fixed), whose centers at any instant are at G and s. The eyepiece O will therefore describe a similar curve of twice the radius about G as a center, and in order to avoid this large range of motion, as well as the long arm GO, we may place a reflecting mirror at C, Fig. 3, between G and Q and return the diffracted rays to an eyepiece O placed near G, as in the mountings shown in Figs. 12 and 13, Plate XVI., of the article previously referred to.

Whether s or r may be more conveniently fixed in position depends on the nature of the comparison desired. If simply a

[1] See Reuleaux's *Kinematics of Machinery*, and Ziwet's *Theoretical Mechanics*, Vol. I, Sec. 6.

comparison between two sources of light as a whole is wanted, and it is desirable that the spectra shall be as bright as possible, it is best to fix the slit in position and form an image of the source upon it by a condensing lens *L* placed beyond the comparison source or prism. If the comparison source is light and easily movable (a Geissler tube or a spark gap between metal poles, for example) both it and the comparison prism may be mounted directly on the pivot at *r* and moved in and out together. The comparison source may be placed either at one side of the prism as is usually done, or better, just below it and at right angles to the slit, as shown in Fig. 4, this last arrangement enabling the whole length of the tube to be utilized and interfering less with the light from the direct source. The best results will usually be secured when the light which falls on the comparison prism or mirror is made slightly convergent by a short focus lens *l* placed between the prism and the source. If it is desired to use the instrument as a compound spectroscope in conjunction with either a refractor or reflector, it would be best to put the comparison prism, source, etc., inside the telescope tube (as indicated by dotted lines in Fig. 3), the pivot at *r*, which supports them, passing through a slot in the tube and connecting with the links *rb*, *rd*, which of course remain outside. The telescope should be adjusted in right ascension (the slit being placed parallel to the motion in right ascension), until the cone of light from the star just grazes the edge of the comparison prism.

This general form of mounting (slit fixed, comparison prism movable) is, as has already been stated, well suited to direct comparison of the two spectra from different sources, but if it is desired to compare the spectra from adjacent parts of the same source, for example, from a Sun-spot or facula and the neighboring photosphere, or from the equatorial and polar regions of a planet, it is necessary that the image of the source shall be formed not on the slit plate as before but at the pivot *r* in front of the slit.

Since the image could only be moved by moving the con-

densing lens by which it is formed, and since this would in general be inconvenient and in an astronomical spectroscope impossible, it is best in this case to fix the pivot r in position, the slit and grating sliding toward and from it. The use of the concave grating in this way brings out one thing to which attention has not yet been called, *i. e.*, that although the spectral images from different portions of the source are well defined in a vertical plane, the image of any particular horizontal element is the integrated effect of the whole of that element, and hence, if the different portions of the source differ from one another in a horizontal direction as well as vertically, it is necessary to limit the width of the image at r to that portion of the source across which the radiation is homogeneous by a second slit parallel to the regular slit at s. This of course cuts down the quantity of light which falls on the second slit and the grating, the loss being greater as the angle of incidence i increases, and thus detracts considerably from the usefulness of the instrument for this particular purpose, except in the case of very bright sources such as the Sun. This instrument has another characteristic which is of importance in the study of approximately monochromatic and homogeneous sources of radiation, like the solar prominences. On account of the integrating effect at right angles to the slit, which has just been mentioned, no direct images of such sources can be obtained, as with the ordinary spectroscope, by opening the slit, and we cannot, therefore, study the *forms* of the prominences by this method. On the other hand we can determine with great readiness the *average* variations in density and structure of the prominence either in altitude or along the limb. For the first purpose the prominence is brought upon the screen or diaphragm at r in the position shown in Fig. 5, Plate VII., in which the heavily shaded portions represent the surface of the screen upon which the image falls, s_1 s_2 the slit or rectangular opening on which the prominence falls, the dotted lines down its center indicating the position of the spectroscope slit s, which lies behind it. Each point in the height of the resulting prominence spectrum will then be derived from a corresponding

PLATE VII.

Fig. 5

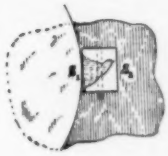


Fig. 6

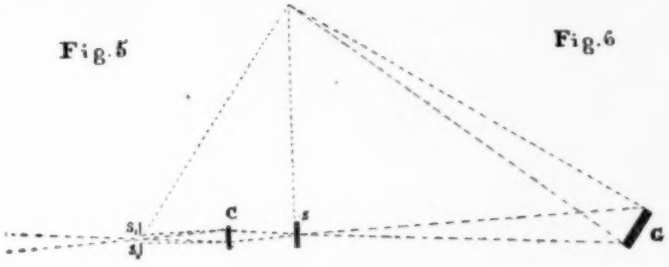


Fig. 7

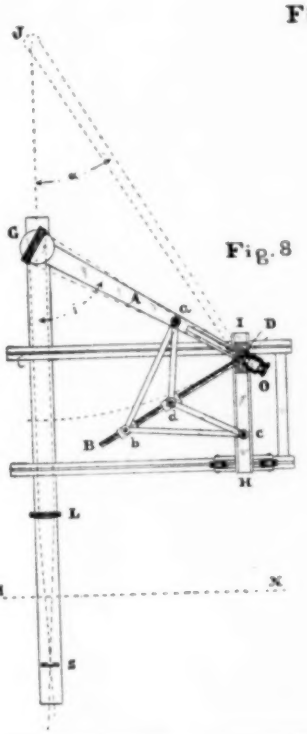


Fig. 8

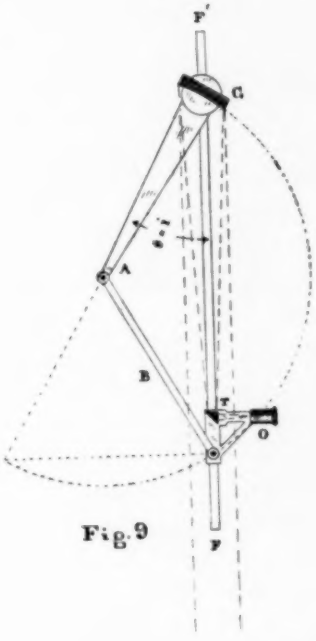


Fig. 9

horizontal or tangential strip across the prominence and will therefore have a width and position which depends on the average density of the prominence at that altitude and the motions, if any, in the line of sight. To analyze the prominence radially or along the limb, it must be brought on the first opening in the position in Fig. 6. In either of these cases we can utilize the light from the whole prominence and thus obtain a very bright spectrum by inserting a cylindrical lens *C*, Fig. 7, between the first opening $s_1 s_2$ and the slit s, the axis of the lens being parallel to the length of the slit and therefore without effect on the vertical definition of the source at $s_1 s_2$. This increase in brightness resulting from the use of the whole prominence without increasing the width of the slit may be of advantage also in studying the prominence spectrum as a whole, and may even enable the coronal line to be seen and studied without an eclipse.

A universal mounting of the preceding type which has recently been finished is shown in Plate VIII.[1] Its construction and method of operation will be readily understood from the preceding discussion and the following brief description. The slides are formed by two long rods of ¾ in. cold-rolled steel, which are supported geometrically on V's planed in three equidistant cross bars which are carefully aligned and leveled. Three geometrical slides carry the grating carriage, the slit and its accessories, and the comparison prism, with the attached Geissler tubes, etc. Any one of them may be geometrically clamped in position, the others remaining free. The long links, *a b*, *a d* of Fig. 2 are each 6 ft. 3 in. long and the short ones, *b c*, *c d*, *d c*, *c b*, 3 ft. 9 in., allowing a range of motion from $i = 0$ to $i = 60°$ for which *G r* or *a c* equals 10 ft. or 2ρ. The vertices *b*, *d* of the cell are upheld by long, light, spiral springs attached to the ends of a cord which passes over a pulley fixed to the ceiling of the laboratory. The links themselves are of well-seasoned pine ½ in. by 1⅛ in., to the ends of which are screwed brass bushings working on accurately turned steel pins. As

[1] The mounting is for a small five-foot grating kindly loaned to me by Professor Hale for these experiments.

shown in the photograph, the apparatus is set up for use with an electric arc and Geissler tubes, the screen and prism carriage at *r* being fixed, and the grating and slit movable. The apparatus is also arranged so that the long links may be readily disconnected and the grating used in the usual way, the image of the source being formed directly on the slit *s*. The mounting in this case becomes the same as that figured in Plate XVI. of my last article. Finally, as there suggested, the link *B* connecting the end of the grating arm and slit, may be disconnected, a collimator placed on the Y's shown attached to the grating track just in front of the grating carriage in the photograph, and the plane mirror on the grating arm either replaced by a concave, or the eyepiece at *o* replaced by an observing telescope, thus making the mounting suitable for use with a plane grating or prism train. When used with the concave grating the adjustments are made in the same manner as with the ordinary Rowland mounting, the reflecting mirror being first removed and afterwards replaced and adjusted to return the diffracted rays to the eyepiece at *O*. The mounting has been finished only a short time, but so far has proved very satisfactory.

The smoothness and ease of motion is especially apparent. For gratings of larger radius of curvature than 10 ft. the length of the links *a b*, *a d*, would become inconveniently great and it would therefore be desirable to modify the construction by bisecting all of the links of the system, as in the mounting of Fig. 13 of the Plate just referred to. This gives us the linkage shown in dotted lines in Fig. 2, which is evidently exactly equivalent to the linkage of Fig. 3, but is very much more compact as well as more symmetrical.

In the study of the subject of analyzing concave gratings another method of use has suggested itself which is so simple that it seems as though it must have been pointed out before, although I have not been able to find any mention of it in the papers of those who have written on the subject.

If we call *R* the distance of the source from the grating and

PLATE VIII.

F the distance from the grating to the point on its axis at which the source at R is well defined horizontally, then, as has been shown by Sirks,

$$\frac{1}{R} + \frac{1}{F} = \frac{1 + \cos i}{\rho}$$

whence,

$$F = \frac{\rho}{1 + \cos i - \frac{\rho}{R}}. \qquad (1)$$

On the other hand the coördinates of the point r, θ, at which the *spectrum* is in focus are given by the well-known relation

$$r = \frac{\rho \cos^2 \theta}{\cos \theta + \cos i - \frac{\rho}{R} \cos^2 i};$$

when the point r lies on the axis of grating or $\theta = 0$, this becomes

$$r_0 = \frac{\rho}{1 + \cos i - \frac{\rho}{R} \cos^2 i} \qquad (2)$$

and by comparing (1) and (2) we readily see that F becomes equal to r_0 for all values of i when $R = \infty$, or in other words, the visual and spectral foci of the grating coincide when the rays incident on the grating surface are parallel, as they would be if the grating were turned directly on a star or on the Sun. In the case of a star or planet this would be the simplest possible arrangement, the source being so small that the spectral lines will be well defined, but in the case of the Sun, which has an angular magnitude of nearly ½°, a different plan must be adopted, viz., that of using an intervening slit on which the solar image is formed and inserting a collimating lens or mirror between this slit and the grating, to render the rays again parallel. This has the disadvantage, it is true, of decreasing the simplicity of the grating train by the introduction of a lens or concave mirror, but it has the advantage over the first arrangement described of rendering the first screen or slit unnecessary, and enabling the spectra of successive points in a very narrow vertical strip of the Sun's surface to be com-

pared just as in an ordinary plane grating or prism spectroscope, to which it is superior in that the observing telescope at least is rendered unnecessary.

From equation (2) we have for $R = \infty$

$$r_0 = \frac{\rho}{1 + \cos i}$$

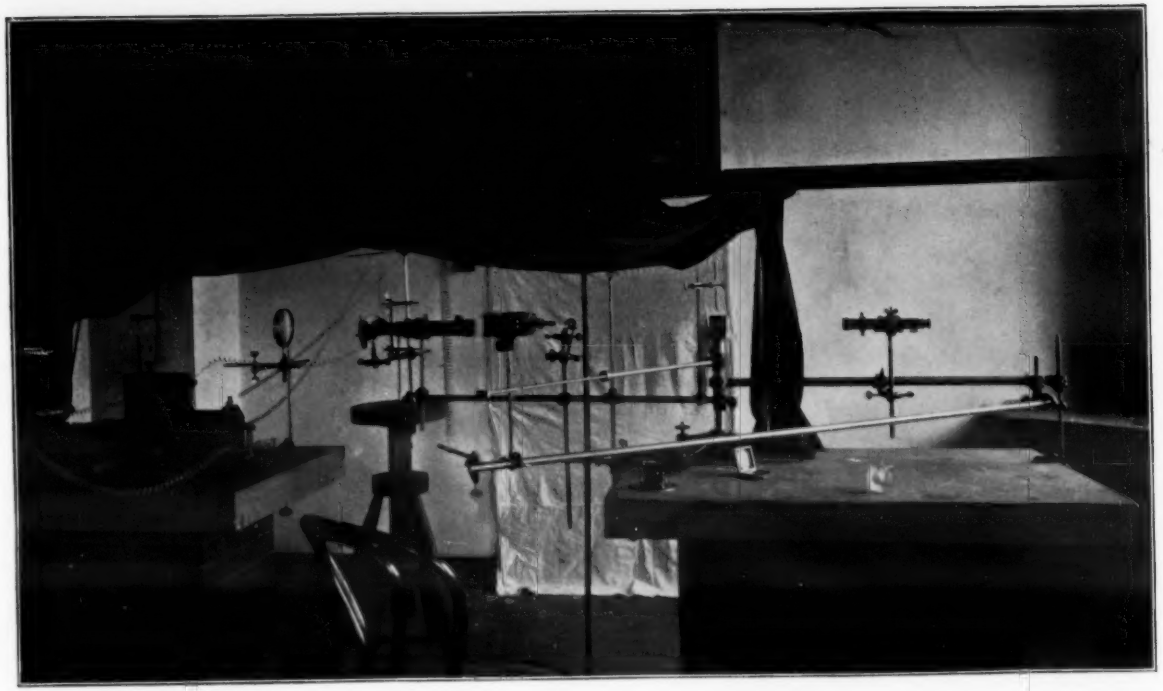
which is the polar equation of a parabola, the focus being the pole and the radius of curvature ρ being one-half the latus rectum. To keep the spectra in focus we must therefore move the eyepiece along the arc of a parabola of which the focus is the center of the grating, and the axis, the line of collimation $s\,L$, Fig. 8. This can be accomplished exactly by the link work mounting shown in Fig. 8, in which G is the grating mounted on the radius arm, $G\,A$, L the collimating lens and s the slit. The eyepiece O is mounted at the end D of an arm $B\,D$. The end D is pivoted to two slides, one of which moves along the track $H\,I$, parallel to the axis of the parabola, and the other in the radial slot in $G\,A$, normal to the grating; the eyepiece, therefore, always lies at the intersection of the center of the track and the axis of the slot. To keep this point of intersection on the parabola it is then only necessary to add the two pairs of equal links $a\,b$, $b\,c$, and $a\,d$, $d\,c$, whose outer ends are pivoted to $G\,A$ and $I\,H$ at equal distances, respectively, from the focus G and the directrix $M\,N$, and whose inner ends are pivoted to the collars b, d, sliding on $B\,D$; and mount the slide $I\,H$ on tracks parallel to $M\,N$. Then it is evident that as the track $I\,H$ is pushed along, the distance of D from $M\,N$ must always remain equal to $G\,D$, since the arm $B\,D$ always bisects the angle $G\,D\,H$ and the triangles $a\,b\,D$ and $c\,b\,D$ are therefore similar.

Further, the arm $B\,D$ always lies along the tangent to the parabola at the point D, and hence, if a photographic plate is mounted with its length paralllel to $A\,D$ the spectrum will be in focus over the whole length of the plate.

The spectrum, however, will not be normal at D.

For we have from the theory of the grating—

PLATE IX.



$$\Delta\lambda = \frac{1}{nN}\cos\theta\,\Delta\theta = \frac{1}{nN}\Delta\theta.$$

But from the equation of the parabola we have

$$dr = \frac{r^2}{\rho}\sin i\,di = \frac{r^2}{\rho}\sin i\,d\theta;$$

and since $$r\,d\theta = \sqrt{ds^2 - dr^2},$$

we get by substitution

$$d\theta = \frac{ds}{r\sqrt{1 + \left(\frac{r}{\rho}\sin i\right)^2}}$$

and $$\Delta\lambda = \frac{1}{nN}\,\frac{\Delta s}{r}\,\frac{1}{\sqrt{1 + \left(\frac{r}{\rho}\sin i\right)^2}}$$

which expresses the variation in wave-length as we go along the focal curve.

The preceding motion is exactly parabolic for all values of i. But in the use of the grating i rarely, if ever, exceeds 60° and for this range the parabolic curve coincides almost exactly with the arc of the circle, drawn about J, Fig. 8, as a center. A much simpler mounting is therefore obtained by mounting the eyepiece on the end of the arm $J\,D$, this arm having a pin which engages with the slot in $G\,A$. The small variation from the true parabolic curve is readily compensated by sliding the eyepiece slightly in or out. In the case of a five-foot grating, the radius arm $J\,D$ is about 65 in. long, and the variation from the true focal curve does not exceed 0.1 in. at any point up to $i = 60°$. A photographic reproduction of a mounting constructed on these lines is shown in Plate IX. Its construction and method of operation will be readily understood from the plate and from the preceding description. The telescope shown at the left of the plate is the collimator, and the small one at the right is for focussing the large one and for the preliminary adjustment of the grating to perpendicularity to the line of collimation. The only other adjustments required is to place the grating so that its center is on the axis of rotation (accomplished very conveniently by rotating the grating under a fixed point or microscope, just above

the grating table), and so that its axis is parallel to the arm $G\,A$ (accomplished by reflection of a candle flame placed near D). The performance of this mounting has also been very satisfactory, and it is hoped that some results obtained with it may be shortly ready for publication.

There is one modification of the third general case discussed in my preceding paper, viz., that in which the grating is simply rotated on its axis, the slit and eyepiece both remaining fixed; that deserves special attention in this connection because of the extreme simplicity and beauty of the solution under the condition that was assumed in the case just considered, that of a source of light at an infinite distance. Let us assume that the angle θ is made equal to the angle i, or that the angle ϕ in Fig. 4, Plate XIV. (*Ap. J.* December, 1895) is zero. Then the general equation (4) p. 375, becomes

$$R = \frac{\rho \cos i}{2 - \frac{\rho}{r} \cos i},$$

or

$$r = \frac{\rho \cos \theta}{2 - \frac{\rho}{R} \cos \theta}.$$

The mounting which satisfies these conditions will be very similar to those of Figs. 1 and 3, Plate XIII. But if we make $R = \infty$ we then obtain the very simple solution

$$r = \frac{\rho \cos \theta}{2}.$$

which shows that the spectra all lie on a circle of diameter $\frac{\rho}{2}$. To keep the spectra continually in focus at the eyepiece it is, therefore, only necessary to maintain the grating and eyepiece always on the circumference of a circle of radius $\frac{\rho}{4}$, and further (to maintain the condition of equality of angle of incidence and angle of refraction), keep the chord of the circle which joins them parallel to the incident light. This may be done by a Rowland mounting of just one half the dimensions usually

employed for a given grating, the eyepiece being placed in the position usually occupied by the slit and the latter dispensed with. A more compact arrangement, designed on the lines of the mountings shown in Plate XVI. (*Ap. J.* December, 1895), is shown in Fig. 9, where G is the grating set perpendicular to the length of the first link A, and r and O the reflecting prism and eyepiece attached to a carriage pivoted to the end of the second link B. Either the eyepiece may be fixed and the grating made movable along the track FF', or, if the latter is very large and heavy, it may be fixed and the eyepiece carriage made movable. If the grating is of very long focus the links may be bisected, as already described, but even with a 21-foot grating the two links of this mounting would each be only a little more than five feet in length. The spectra are not normal but the law of variation along the tangent to the focal curve is somewhat simpler than in the case of the plane grating. We have, in this case,

$$\Delta\lambda = \frac{2}{nN}\cos\theta\, d\theta .$$

But

$$d\theta = \frac{ds}{r}\cos\theta = 2\,\frac{ds}{\rho};$$

$$\therefore \Delta\lambda = \frac{4}{nN\rho}\cos\theta\,\Delta s.$$

But if we set the eyepiece with its axis parallel to the direction of the diffracted ray, the spectrum in the field of the eyepiece becomes normal. For if D be the distance through which the micrometer moves for one division in the head, we have for the relation between this distance and the projected distance on the arc of the circle on which the spectrum lies

$$D = ds\cos\theta \text{ or } ds = \frac{D}{\cos\theta}.$$

$$\therefore \Delta\lambda = \frac{4}{nN\rho}\frac{D}{\rho}.$$

as in the ordinary mounting.

Similarly in the case of photographs we could obtain normal spectra by projecting each photograph on another plate at an angle θ with the first.

This mounting is astigmatic and is not therefore suited to the purposes for which the preceding forms have been designed. But it would seem particularly well adapted for a direct stellar spectroscope used without a telescope, both on account of its simplicity and compactness and on account of this very property of astigmatism which is, as has already been pointed out, a decided advantage for stellar spectroscopic work.

In order to secure sufficient brightness the concave grating would have to be larger than those now in use, at least as large as the objective of the telescopes now commonly employed for the compound spectroscopes, and it would therefore be best to fix the axis of the grating in position and make the eyepiece movable.

In this class of work it is, as has already been pointed out,[1] a decided advantage to also make the angular aperture of the instrument much larger than is usually done, not less than $\frac{1}{10}$ and preferably even $\frac{1}{8}$ or $\frac{1}{5}$. In the case of the concave grating, however, the effect of aberration increases as the cube of the aperture (when mounted in the usual manner) and even more rapidly when mounted in the manner just described.

With a 6″ concave grating of 21 feet radius of curvature this effect has been shown by Rowland to amount to less than one part in a million for extreme angles of diffraction,[2] and less than one part in 5000000 in the first spectra.

With a grating of an angular aperture of $\frac{1}{10}$ the effect would be between 125 and 150 times as great and with one of an angular aperture of $\frac{1}{5}$, 1000 to 1200 times as great. But since a very high degree of resolution is not necessary in the case of stellar spectra (the spectroscopes now commonly employed in this work have a resolving power, not usually exceeding 15,000 to 20,000),

[1] *Ap. J.*, January, 1895, 1, 70.

[2] "Concave Gratings for Optical Purposes," H. A. Rowland, *Am. Jour. Sci.*, 3d Ser. **26**, 97.

the ruling on these large gratings could be quite coarse (100 lines per mm. would give with a 30^{cm} aperture a resolving power of 30,000 in the first order), and the resulting angle of deviation small. It would moreover be best to use the first order spectra in order to best utilize the full grating aperture. The angle of deviation therefore would not need to exceed 5° to 10°, and the effect of aberration would therefore not be greater than one part in 20,000, even for an angular aperture of $\frac{1}{6}$, or just about the limit of the resolving power of the grating. But this may be still further reduced if necessary by slightly increasing the grating space as we go towards the edges, either by changing the step of the dividing engine or more conveniently by ruling the grating on a parabolic instead of a spherical surface. There is therefore no inherent difficulty in applying these large short focus gratings to such work, and the advantages which they would have over all other forms of stellar spectroscopes would well repay the preliminary difficulties which would be encountered in their ruling.

It is also of interest to consider in this connection the question of the objective grating spectroscope or object glass grating. This instrument has recently been discussed by Jewell,[1] who has proposed a very ingenious method of making such a large transmission grating by photography. It would seem however that in the case of very large telescopes, the Lick and Yerkes, for example, this method would be impracticable because the plates upon which the grating is photographed would have to be of the same quality as the objective itself, otherwise the definition would be injured. The use of the plates might be avoided by photographing the grating directly on the surface of the objective, but this would be a process which would be attended with more or less danger and trouble, besides unfitting the objective for other purposes for the time being. Since the very large size of these instruments would necessitate only a very coarse ruling in order to obtain the necessary resolving power it would seem possible that the desired result might be very readily attained

[1] "The Object Glass Grating," *A. and A.* 13, 44, January 1894.

by the use of wire gratings made according to Fraunhofer's original plan of winding fine wire upon two parallel screws of very fine pitch. With a telescope of the size of the Yerkes a grating interval of $\frac{1}{10}$ mm. would be fine enough to obtain a resolving power of 10,000 in the first order, and it is perfectly easy mechanically to wind a grating of even twice this or twenty wires per mm. with suitable wire and suitable appliances. For $\frac{1}{10}$ mm. intervals comparatively large and strong wire (No. 38 American, or 40 B. W. G.) could be used, and the danger of any injury to the grating in handling thus minimized. Such a grating would also be comparatively inexpensive and very useful in the preliminary study of types of stellar spectra preparatory to the use of the great compound spectroscope to be provided for this instrument.

UNIVERSITY OF CHICAGO.
November, 1895.

Minor Contributions and Notes.

RECENT RESEARCHES BEARING ON THE DETERMINATION OF WAVE-LENGTHS IN THE INFRA-RED SPECTRUM.

The relation between the refractive index of a substance and the wave-length of the corresponding refracted ray is one of great interest in physics, not only on account of its bearing on optical theories of dispersion, but because it must be used by the investigator of obscure heat spectra in order to determine the wave-lengths of rays observed with his prism of rock-salt or other diathermanous material. By means of photography the solar spectrum has been accurately mapped with diffraction gratings as far as $1^{\mu}.2$, and traced, with insufficient accuracy for measurement, to about $2^{\mu}.7$, but below this point the heating effect of the spectrum must be utilized. In general the grating cannot be employed in the investigation of these extreme wave-lengths, on account of its wastefulness; with specially powerful sources of radiant energy it can, however, be used to *calibrate* a prism, which then becomes available for wave-length determinations with radiant sources of moderate intensity. Other methods of calibrating a prism have also been devised which do not require the use of a grating.

Such measures in the invisible spectrum combined with visual or photographic observations of the Fraunhofer lines, allow a table to be constructed giving the refractive indices of the prism and their corresponding wave-lengths throughout a great range of the spectrum. A table of this kind, if made from reliable observations, is of great value for testing formulæ of dispersion. It also enables other observers who employ prisms of the same material to find at once the wave-lengths of the rays which they measure, and it therefore finds immediate application in all investigations relating to the laws of radiation by bodies at comparatively low temperatures. The present article gives an account of recent work of the kind indicated above, chiefly with reference to its value from the standpoint of the observer.

It is not necessary to specially mention the earlier investigations by which the measurement of rays in the lower spectrum was pushed to a

considerable distance below its visible limit. All previous attempts in this direction were surpassed in 1884–6 by Professor Langley,[1] who, employing a large Rowland concave grating of short radius in connection with a rock-salt prism, and the electric arc as a source of radiation, measured the heating effect in the prismatic spectrum, by means of the bolometer, down to a wave-length of $5^{\mu}.3$. The curve for rock-salt, representing the index of refraction as a function of the wave-length, which he was enabled to draw by means of these observations, extends to this point, and its accuracy has been confirmed by all more recent investigations.

The main object of the observations was to determine the wave-lengths of absorption bands which had been discovered in the prismatic solar spectrum, but Professor Langley also used the material he had gathered to test a number of dispersion formulæ. Of these formulæ, which are deduced from theories founded on various assumptions as to the nature of the interaction between the ether and the molecules of the refracting substance, those of Cauchy and Briot are perhaps the best known. The former, in its shorter form, represents the dispersion in the visible spectrum with considerable accuracy, and is much used for interpolating wave-lengths when the intervals are short, even where great precision is required. Langley's method of testing was to determine the constants in the formulæ from observations of lines in the visible spectrum, and then to compare extrapolated values in the infra-red with the values deduced from his measurements. The result was that none of the formulæ were satisfactory. A similar test of dispersion formulæ by Brühl[2] led to the same conclusion.

To such methods of procedure Ketteler[3] has objected strongly. All the observations are necessarily affected with errors, which in some cases may have a great influence on the form of the curve determined from them, and the greatest care must be taken to employ reliable pairs of values of n and λ. In the tests mentioned above it does not appear that the points were always well selected, and a formula representing $n = f(\lambda)$ with erroneous constants derived from faulty values cannot be expected to represent the true dispersion curve. Ketteler's more circumspectly performed extrapolations are much more successful, but he regards the question as having little physical interest. His own formula

[1] S. P. LANGLEY, *Mem. Nat. Acad. Sc.* 1883. *Ann. Chim. et Phys.* (6) **9**, 433, 1886.

[2] J. W. BRÜHL, *Liebig's Ann. der Chemie*, **236**, 233, 1886.

[3] E. KETTELER, *Wied. Ann.* **30**, 299, 1887.

(given further below in the present article), in which the effect of absorption on dispersion is taken into account, represents Langley's observations well, although the absorption of rock-salt is so slight that the test of the theory is not a conclusive one.

As Langley's measurements in the spectra of heated bodies extended below 5μ.3, he sought to determine wave-lengths greater than this by a straight line extrapolation, continuing the dispersion curve by a tangent drawn at its lowest observed point, supposing that in this way at least minimum wave-lengths of the observed rays would be obtained. According to this process the wave-lengths of points at which heating effect could still be detected with a rock-salt prism exceeded 30μ. The dispersion curve for rock-salt determined by Langley was adopted by Julius and by Ångström in their important investigations on the radiation and absorption by heated gases.

Not only were the instrumental means employed by Langley more powerful than those of his predecessors, but the method was distinctly superior to any that had been tried by them. The rays from the carbon of an electric arc fell first upon the grating, which was mounted on Rowland's well-known plan. The spectrometer, with rock-salt prism and train, was placed so that the spectrum of the grating fell upon its slit, through which therefore passed rays whose wave-lengths were known by the theory of the grating. By the prismatic train these rays were separated so as to form a series of images of the slit, each image belonging to a different order of grating spectrum, and their deviations by the prism were ascertained by means of the bolometer. In earlier investigations of wave-lengths the prism train had been placed first.

An entirely different method was used by Rubens[1] in 1892. The grating was dispensed with, and artificial cold bands of known wave-length were produced in a continuous spectrum, by interference. The positions of these bands, *i. e.*, their deviations by the prism, were measured by a linear bolometer. The interference was obtained by causing the rays from a zirconia burner, before they reached the spectrometer slit, to fall upon two plates of glass placed nearly in contact, so that the rays reflected from the inner surfaces pursued paths of slightly different length. By changing the distance between the plates, the intervals between the interference bands could be altered at pleasure. In some of the experiments the outer glass plate was replaced by a similar plate of fluorite.

[1] H. RUBENS, *Wied. Ann.* **45**, 238, 1892.

The method of producing interference bands in a continuous spectrum had been previously used by E. Becquerel [1] for determining wave-lengths in his phosphorescent infra-red spectra, and by Mouton; but in these experiments the bands were produced by a plate of quartz between two polarizing prisms, and the spectrum was much weakened by the absorption of the apparatus.

Rubens determined the relation between the wave-lengths and refractive indices for glass, carbon bisulphide, quartz, water, benzol, fluorite and rock-salt, and platted the corresponding curves, which in most cases do not extend beyond $2^{\mu}.0$ or $2^{\mu}.5$. The curve for rock-salt, however, is given as far as $5^{\mu}.75$. It agrees closely with Langley's curve, and is nearly straight below 2^{μ}.

The curves for a number of the other substances exhibit some remarkable and interesting peculiarities. Those for xylol and benzol tend continually to a horizontal direction, as if they had an asymptote parallel to the axis of λ, like that required by Cauchy's formula. The curve for water has little curvature in the infra-red as far as $1^{\mu}.25$, where the observations stop. The dispersion therefore changes but little, throughout the whole range of the measurable spectrum. The curves for the other substances have points of inflection in the infra-red, beyond which the curves become concave toward the axis of λ; hence the dispersion, after diminishing to a certain point, again increases. This peculiarity, presumably the effect of absorption which is indicated by Ketteler's theory, seems to be here experimentally recognized for the first time. It is most noticeable in the case of glass, and does not appear at all, according to Rubens, in the curve for rock-salt.

The same method was employed by Rubens and Snow [2] in 1892 for determining the dispersion of rock-salt, sylvite and fluorite, but the apparatus was considerably improved. The plates for producing interference were larger (4^{cm} square) and the outer one was of fluorite; the optical train was composed entirely of fluorite and rock-salt, and the width of the bolometer strip was only $\frac{1}{12}^{mm}$.

With this improved apparatus the curve for rock-salt was determined as far as $8^{\mu}.3$, but according to the measurements it was still convex toward the axis of λ, rising slightly above Langley's straight-line extrapolation. As these measurements seem to have been affected

[1] E. BECQUEREL, *Ann. Chim. et Phys.* (5) **10**, 5, 1877.

[2] H. RUBENS and B. W. SNOW, *Wied. Ann.* **46**, 529, 1892; *A. and A.* **12**, 231, 1893.

by errors, subsequently corrected, they need not be described further. The curve for sylvite is quite similar to that for the chemically related rock-salt, but the dispersion falls off more rapidly toward the infra-red. The curve for fluorite, which was traced with difficulty below $3^{\mu}.5$ as far as 8^{μ}, is very different from either of these. The reversal of curvature at about 2^{μ} is strongly marked, and the dispersion beyond that point is very great, nearly equaling, in fact, the dispersion in the visible spectrum. For this reason and for the practical one that its surfaces are permanent when exposed to the air, fluorite is particularly well adapted to the production of prismatic heat-spectra.

Compared with the method of determining wave-lengths, which was first described, the method of interference bands is inferior in a number of different respects. The bands have considerable width, and the minima are not sharply defined. Moreover, it is evident that if the band falls at a place where the distribution of energy in the spectrum is not uniform, the minimum heating effect will not be obtained when the center of the bolometer strip coincides with the darkest part of the band, but when it is displaced slightly toward the side of feebler energy. The error due to this cause becomes less, the narrower the bolometer strip which is used, but the uncertainties due to the breadth of the diffraction bands are not avoided by the use of a narrow strip. Methods of correcting the positions of the minima have been given by Rubens and Paschen. With Langley's apparatus, on the other hand, the maximum heating effect is obtained when the bolometer strip and the deviated image of the slit are in exact coincidence, provided their width is the same, whether the distribution of energy in the image is symmetrical or not. Hence a fairly wide slit and bolometer can be used without impairing the accuracy of the measures.

Carvallo,[1] by an ingenious modification of a method formerly used by Mouton, has succeeded in overcoming both the difficulties mentioned above. The diffraction bands are produced, as in the older method, by a plate of quartz between polarizing prisms; but the analyzer is double-refracting, and thus two complementary spectra are formed, one above the other, traversed by interference bands. A bright band in one spectrum is the prolongation of a dark band in the other. The narrow thermopile employed was placed across both spectra, and points were determined at which the heating effect on both ends was the same. The wave-lengths of such points are equally determinable

[1] E. CARVALLO, *C. R.* 116, 1189, 1893.

by the wave-theory, and they are much more sharply marked than the minima. In this way Carvallo measured the dispersion of fluorite with considerable accuracy down to a wave-length of $1^{\mu}.849$, the absorption of the apparatus preventing any lower measures.

In order to avoid the difficulties and uncertainties attending the transformation of prismatic into normal energy curves, F. Paschen[1] in 1893 attempted to measure directly the distribution of energy in grating spectra, the source of radiation being an incandescent carbon filament. In his apparatus lenses were avoided and reflectors were used. The result of many experiments with different gratings was, that the energy curves were always irregular; that some of these irregularities depended upon the grating, while certain well marked depressions were always found at the same places, no matter what grating was used or what other changes were made in the apparatus.

The cause of the irregularities first mentioned is now well known. An actual reflecting grating does not consist of alternate reflecting and absolutely black strips, as supposed in the elementary theory, but of a corrugated surface, all parts of which are capable of reflecting light. The theory of a grating with grooves of triangular section was worked out by Quincke in 1872, while the complete theory of gratings with grooves of various forms was given by Rowland,[2] who showed that under certain conditions not only were the different orders of spectra of greatly different intensities as compared with one another, but that the intensity might be far from uniform in any one order, so that a spectrum might, for instance, be strong in the red, and at the same time weak in the green. As Paschen remarks that physicists seem to have been of the opinion that a good grating can be relied upon to give a useful normal energy curve, it may be well to emphasize the fact that the ordinates of a grating energy curve depend upon a special peculiarity of the grating, as well as upon the nature of the radiant source.

It was remarked by Kayser and Runge,[3] in their work on the spectra of the elements, that with one of their large concave gratings the spectrum suddenly terminated at a certain wave-length in the ultra-violet.

The only explanation of the constant minima that Paschen could give was that they were caused by the absorption of gases in the air

[1] F. PASCHEN, *Wied. Ann.* **48**, 272, 1893, and **51**, 1, 1894.

[2] H. A. ROWLAND, *A. and A.* **12**, 189, 1893; *Phil. Mag.* **35**, 397, 1893.

[3] H. KAYSER and C. RUNGE, *Abh. d. K. Akad. d. W. Berlin*, III., 17, 1888.

(water vapor and carbon dioxide). It was necessary to suppose that the absorption was very strong, since varying the quantity of the two gases in the room did not appreciably affect its amount. Further experiments showed that it was impossible to obtain an unbroken energy curve, even with a prism, unless the air was carefully purified from carbon dioxide and water vapor. It was evident that large errors might be committed if an energy curve were determined by measurements at a few points in the spectrum, without taking these absorption minima into account, and their existence seemed to have been unnoticed by previous investigators.[1] Paschen gives the wave-lengths of the principal bands of CO_2 and water vapor, the values differing but little from those of K. Ångström, who used Langley's curve for rock-salt, and somewhat more widely from those of Julius.

The bands of Langley's infra-red solar spectrum are identified as follows:

Langley's ω at 1$^{\mu}$.4 is water vapor.
" Ω " 1 .83 " "
" X " 2 .64 " "
" 2 .94 corresponds to band of liquid water.
" Y " 4 .6 is carbon dioxide.
" 5$^{\mu}$ to 11$^{\mu}$ corresponds to the strong water vapor absorption band with maxima at 7$^{\mu}$.1 and 8$^{\mu}$.1.

Paschen[2] attributes the discrepancies between his values for the wave-lengths of the atmospheric bands and those of Ångström and Julius to errors in the dispersion curves, particularly in the curve for fluorite. In the energy curve of Rubens and Snow several of the lowest observed interference minima nearly coincide with the absorption minima referred to above, and this is particularly unfortunate, since the lowest points are of great importance in determining the course of the dispersion curve. The probability of error in the curve is increased by the fact that the observers were unaware of the existence of these absorption bands.

This explanation is also accepted by Rubens,[3] who found it impossible to represent satisfactorily his earlier results, and those of Carvallo, with which they agree well, by Briot's formula. The method of artificial cold bands is defective in the extreme infra-red, not only for the

[2] See, however, the note by F. W. Very, in this JOURNAL, **2**, 237, 1895.

[1] F. PASCHEN, *Wied. Ann.* **51**, 1, 1894.

[3] H. RUBENS, *Wied. Ann.* **51**, 381, 1894.

reason pointed out by Paschen, but because the interference bands in that region have a great width (reaching 2½°), on account of the high dispersion of fluorite. On the other hand, the method is superior to Langley's in the upper spectrum, where there are no absorption bands, and where the minima are sharply defined. Rubens therefore redetermined the lower part of the dispersion curve for fluorite by Langley's method, using, however, a transmission grating of wire instead of a reflecting grating. The source of light was a zircon burner, and fluorite lenses were used in the optical train.

The grating was made according to a peculiar, and perhaps novel method, which offers several features of interest. Two fine gold wires (about 0.03^{mm} in diameter) were wound together on a double rectangular frame. The wires were pushed together during the winding until no light was transmitted, and when the frame was full one of the wires was unwound. On securing the remaining wire in an appropriate manner, and separating the halves of the frame, two similar gratings were obtained, the definition of which was sufficiently good to permit optical settings to be made in the spectra of the fifteenth order. In general the spectrometer slit was set at random positions in the grating spectrum, but occasionally it was set on the D lines, as in the original method of Langley.

Measures were made with this apparatus down to $6^{\mu}.48$. It was impossible to go beyond this point for the following reasons: 1. The radiant energy of the zircon burner was too small, even when the slit was opened to 1^{mm}. 2. The definition of the spectral lines began to be bad in the high order of the spectrum in which the visual settings had to be made. 3. The chromatic aberration of the fluorite lenses required the readjustment of the draw-tubes of the spectrometer, this change introducing an additional source of error.

Rubens gives a table of the collected results, compared with computed values obtained by Briot's formula with constants given by Carvallo. The new and old measures fit well together, although there is evidence of a slight constant error where they join. The curve of Briot's formula agrees accurately throughout, and as Ketteler[1] has shown that it is also applicable to the ultra-violet, Rubens thinks there is no reason to doubt that it holds down to the beginning of the region of absorption, presumably at or below 9^{μ}. Extrapolated values of n are therefore given for 7, 8, 9 and 10^{μ}.

[1] E. KETTELER, *Wied. Ann.* **30**, 299, 1887.

A paper in which Paschen[1] revises some of his wave-length determinations, using the new dispersion curve of Rubens, is largely devoted to a discussion of the bands of water and aqueous vapor, which is of much interest, although it does not immediately concern the present subject. Methods of correcting the observed positions of minima on the slope of an energy curve are also considered.

By further improving the apparatus already described, Rubens[2] was enabled to extend his measures in the spectrum of a fluorite prism down to 9^{μ}. No lenses were used in the optical train, and the width of the bolometer which was chiefly employed was only $\frac{1}{4}^{mm}$, subtending an angle of $1'.5$ in the spectrum.

Combining with this additional material Sarasin's measures in the ultra-violet, Rubens forms a table containing pairs of values of n and λ for fluorite throughout the whole range of the spectrum, and uses it to test some of the more important dispersion formulæ. As two of these formulæ are much discussed in connection with this and subsequent work, it is desirable to give a short account of them here.

Briot's formula is

$$\frac{1}{n^2} = a + bl^{-2} + cl^2 + dl^{-4},$$

in which l = the wave-length in the refracting substance $= \frac{\lambda}{n}$. The theory on which it is founded (Neuman's) assumes that the molecules of the substance are not set in vibration by the ether waves, and hence refers to perfectly transparent substances; therefore we cannot expect it to hold in the vicinity of a region of absorption, or to explain anomalous dispersion.

Ketteler[3] has deduced a formula from a theory which takes account of the sympathetic vibration of the molecules of the substance, and has shown that it can also be deduced from Helmholtz's electromagnetic theory of dispersion.[4] For two regions of absorption in the spectrum it takes the form

$$n^2 - a^2 = -\frac{M_1(\lambda_1^2 - \lambda^2)}{(\lambda_1^2 - \lambda^2)^2 + g_1^2\lambda^2} + \frac{M_2(\lambda^2 - \lambda_2^2)}{(\lambda^2 - \lambda_2^2)^2 + g_2^2\lambda}, \qquad (1)$$

in which the first of the terms on the right, for which $\lambda_1 > \lambda$, relates to

[1] F. PASCHEN, *Wied. Ann.* **52**, 209, 1894.

[2] H. RUBENS, *Wied. Ann.* **53**, 267, 1894.

[3] E. KETTELER, *Wied. Ann.* **49**, 382, 1894.

[4] H. v. HELMHOLTZ, *Wied. Ann.* **48**, 389, and 723, 1893.

an absorptive region in the infra-red, with strongest absorption at λ_1, and the second term on the right, for which $\lambda_2 < \lambda$, to a similar region in the ultra-violet with strongest absorption at λ_2. M_1 and M_2 are constants, and g_1 and g_2 are the so-called coefficients of friction in Ketteler's theory, appreciable only in the actual regions of absorption; g^2 is very small at a distance from these regions; if we neglect it Ketteler's formula becomes

$$n^2 - a^2 = -\frac{M_1}{\lambda_1^2 - \lambda^2} + \frac{M_2}{\lambda^2 - \lambda_2^2}. \qquad (2)$$

This approximate formula is represented by the four hyperbolic branches in the accompanying figure; between the points a and b it does not deviate appreciably from the complete formula represented graphically by the heavy line.

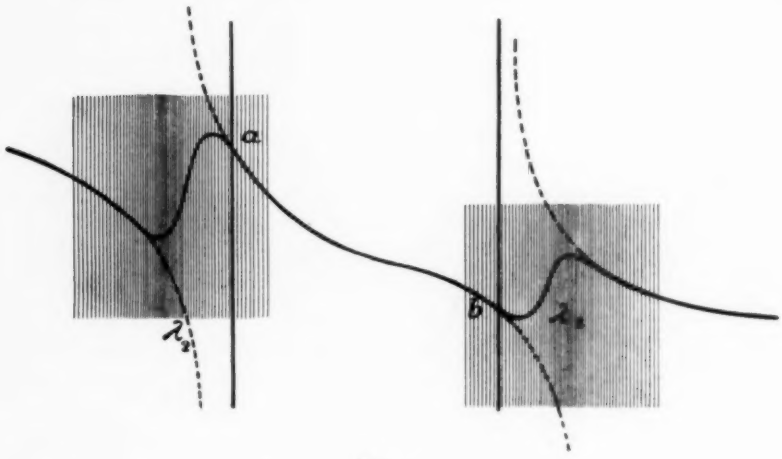


FIG. 1.

If (2) is developed, we obtain the equivalent series

$$n^2 - a^2 = -A - B\lambda^2 - C\lambda^4 - \ldots\ldots + \alpha\lambda^{-2} + \beta\lambda^{-4} + \ldots$$

Hence Ketteler's theory leads to ascending powers of λ^2 as well as to ascending powers of λ^{-2}. Ketteler usually tested his formula in the form

$$n^2 - a^2 = \frac{M_2}{\lambda^2 - \lambda_2^2} - k\lambda \qquad (3)$$

which much resembles Briot's, and found it equal to the latter for

transparent substances. For less transparent substances another term must be added, giving

$$n^2 - a^2 = \frac{M_2}{\lambda^2 - \lambda_2^2} - k\lambda^2 - k_1\lambda^4. \qquad (4)$$

Rubens found that the values in his table were well represented by (3), as well as by Briot's formula.

Having calibrated his fluorite prism, Rubens used it to determine the relation between n and λ for prisms of various substances, by substituting it for the grating and allowing the rays from the zircon burner to pass successively through two spectrometers. On account of the imperfect surfaces of his rock-salt and sylvite prisms, Rubens could not measure the deviations of the visible lines very accurately, and it would seem that the definition in the infra-red must also have suffered. Accurate measures were possible in the case of glass and quartz. Some of the results, which are of much interest, are given below.

The flint glass used has a curve with strong inflection at $1^{\mu}.5$. The formula (3), with constants deduced from the upper spectrum, gives indices much too small in the infra-red.

With quartz (ordinary ray) the inflection is still greater, and the formula deviates widely beyond $2^{\mu}.3$. Even with constants determined from the upper red, (3) could not be made to satisfy the observations; (4) on the other hand, was satisfactory, and the region of greatest absorption according to it is at $\lambda_2 = 10^{\mu}.4$.

Rock-salt (compared with fluorite to $8^{\mu}.95$) also shows a distinct point of inflection, which is, however, not so strongly marked as in the other substances. The results agree with the previous determination by Rubens and Snow as far as 5^{μ}, but below that point there is a rapid deviation, errors already referred to having affected the earlier results. The constants computed by Ketteler from Langley's measures down to $5^{\mu}.3$, when used in formula (3) for extrapolation, give a fair agreement with Rubens' measures, which is still further improved by a slight change in the constants.

Sylvite also shows the inflection in the lower spectrum, its curve resembling that of the chemically analogous rock-salt. The new observations agree with the earlier ones of Rubens and Snow down to 5^{μ}. It is noteworthy that sylvite produces two remarkably sharp absorption bands in the infra-red, one at $3^{\mu}.20$ and the other at $7^{\mu}.08$.[1] Formula (3) represents the observations completely.

[1] These wave-lengths are from a subsequent paper on the same subject.

The general result of Rubens' investigation is that formulæ (3) and (4) are verified by all the observations.

The dispersion of fluorite is also the subject of a paper by Paschen,[1] printed simultaneously with that of Rubens reviewed above. A brief history of previous determinations of infra-red wave-lengths is given, and the methods employed by Rubens are criticised. Paschen doubts the excellence of Rubens' wire grating, and thinks that lenses should not be used in such investigations.

In his own measurements, Paschen used a modification of Langley's method. Lenses were avoided and mirrors used exclusively. The Rowland grating had 142.1 lines per millimeter, with a ruled surface 80^{mm} high and 132^{mm} wide, the radius of curvature being 1753^{mm}. The bolometer strip was $\frac{1}{4}^{mm}$ wide. With such a grating mounted according to the well-known method of Rowland, the dispersion would have exceeded that of the prism fifty times, and the most important improvement on Langley's method introduced by Paschen consisted in reducing the dispersion of the diffraction spectrum by a different arrangement of the grating until it was of the same order as that of the prismatic. In this way so great a saving of radiant energy was effected that a source of moderate intensity could be used. It was found that oxides have an extraordinary radiating power in the infra-red, particularly oxides of iron. According to Paschen, a platinum strip coated with oxide of iron, and brought to a yellow heat, is nearly equal to white-hot carbon for the long wave-lengths, and it exceeds bright platinum from ten to twenty times.

The results of a long series of measurements with this apparatus are exhibited in a table, giving corresponding values of n and λ. The probable error of n for an assumed λ is only a few units in the fifth decimal place,—certainly a remarkable degree of accuracy for measures in invisible heat spectra. On comparing the intensity and dispersion at various points, it appears that with a fluorite prism the long wave-lengths can be more accurately measured than the shorter ones in the infra-red. The influence of absorption on the form of the lower part of the dispersion curve was verified by independent measures of the absorption of fluorite for rays of different wave-lengths.

By comparing the positions of the bands of water vapor in the spectrum of his fluorite prism with the positions of the same bands as

[1] F. PASCHEN, *Wied. Ann.* **53**, 301, 1894.

given by Julius for a rock-salt prism, Paschen[1] obtained an approximate dispersion curve for rock-salt down to $9^{\mu}.4$. The results agree with the later work of Rubens in showing a reversal of curvature in the infra-red.

With the data furnished by his wave-length determinations, Paschen[2] also tested the dispersion formulæ of Briot and of Ketteler. He does not agree with Rubens that the Briot formula represents satisfactorily the dispersion curve of fluorite. But on comparing computed values of n, employing constants derived from the upper spectrum, with the observed values, it was found that the deviation of the formula followed a simple law, and that agreement could be brought about by the addition of a term of the form el^4. The formula then becomes equivalent to Ketteler's, but it is to be noted that a term of this form cannot be derived from the older theory of Neumann.

Ketteler's formulæ (2) and (4) agreed excellently with the observations. In explanation of the different conclusion of Rubens that Briot's formula and (3) are competent to represent the dispersion curve of fluorite, Paschen considers that Rubens' measurements are slightly in error on account of the imperfections of his grating, and maintains the superiority of his own work.

The constants derived by Paschen for formula (2) are as follows:

$a^2 = 6.09104$ $\qquad M_1 = 5099.15$

$\lambda_1 = 35^{\mu}.475$ $\qquad M_2 = 0.00612093$

$\lambda_2 = 0^{\mu}.094256$

In replying to this paper, Rubens considers it probable that the discrepancies between his observations and those of Paschen are due to the differences between the gratings. The grating used by Paschen was no doubt superior to the wire grating used by himself. The discrepancies are, however, quite small. Accepting Paschen's values of n and λ below $2^{\mu}.5$, and retaining his own and Snow's above this point, Rubens readjusts his tables published in *Wied. Ann.* **53**, 267, but the curves are not re-drawn, as their character is not altered by the scarcely perceptible corrections.

With regard to the capabilities of the formulæ, Rubens does not think it permissible to draw *a priori* conclusions from observed values of absorption. By slightly changing the previously determined values

[1] F. PASCHEN, *Wied. Ann.* **53**, 337, 1894.

[2] F. PASCHEN, *Wied. Ann.* **53**, 812, 1894.

of the constants in (3), this formula also can be made to fit the new observations. The accompanying figure shows the dispersion curve for rock-salt, the small circles representing the values of n and λ from the table of Rubens, and the crosses the values which Paschen has derived from a comparison of his own observations with those of Julius.

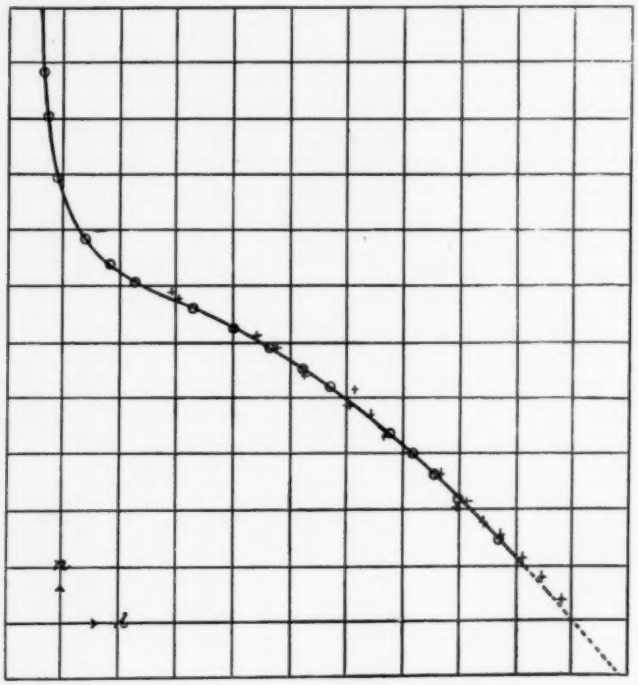


FIG. 2.

The smooth curve represents formula (3), with constants whose values are as follows :

$a^2 = 2.3285$ $\qquad$ $\lambda_s^2 = 0.01621$

$M_s = 0.018496$ $\qquad$ $k = 0.000920.$

This is where the investigation stands at the present time. It is evident that a great advance has been made in our knowledge of infra-red wave-lengths. Although the results of the two principal investigators differ somewhat, they are in sufficiently good agreement to convince us that both are very nearly right. A knowledge of the dispersion of rock-salt is of fundamental importance in all researches on radiant energy in which this substance is employed, and this knowledge

is now supplied by Ketteler's formula (3), with the constants given above, for all wave-lengths that there is usually any occasion to measure. Whether it has been definitely proved that Kettler's formula represents the true physical law of dispersion may be doubted, but it has been shown that the formula is a sufficiently close approximation to the law to answer all the practical purposes of observation.

One result of these researches must surprise those who have used rock-salt prisms. On account of the reversal of curvature of the dispersion curve, all wave-lengths formerly determined by extrapolation beynd 5μ are too large, and in case the extrapolation was an extensive one, very greatly too large. Thus the wave-length of the extreme rays measured by Langley and estimated by him at 30μ is probably not more than 15μ, or perhaps 10μ. It follows that the range of wave-lengths known to us is smaller than it was supposed to be a few years ago. JAMES E. KEELER.

HARVARD COLLEGE OBSERVATORY, CIRCULAR NO. 3.

NEW VARIABLE STAR OF THE ALGOL TYPE.

THE star *B.D.* + 17° 4367, mag. 9.1, whose approximate position for 1900 is in R. A. $20^h\ 33^m.1$, Dec. + 17° 56′, appears to be a variable star of the Algol type. On July 18, 1895, Miss Louisa D. Wells found that no trace of this star appeared on the photograph I 4359, taken with the 8-inch Draper telescope on September 26, 1891, exposure 16^m. On seventy-one other plates taken from June 30, 1890, to October 5, 1895, the star appears of its normal brightness. On December 12, 1895, at $10^h\ 42^m$, Greenwich Mean Time, Professor Arthur Searle, who had watched this star on several nights, found it more than a magnitude fainter than usual. During the next half hour it diminished about half a magnitude more. Meanwhile, a photograph taken with the 8-inch Draper telescope, I 14036, confirmed the diminution in light. Unfortunately, at $11^h\ 15^m$ G. M. T., clouds covered the region, and the star, although carefully looked for, was not seen again that evening. The change in brightness appears to be rapid and the range of variation to be large, exceeding two magnitudes. The nearest bright star is *B.D.* + 17° 4370, mag. 7.0, which follows 14^s and is south 1′. The variability of *B.D.* + 17° 4370 has been suspected by Espin (*English Mechanic*, **62**, 334), and also independently by Mrs. Fleming in 1890. EDWARD C. PICKERING.

December 13, 1895.

Reviews.

Recherches spectrales sur l'ètoile Altaïr. Reconnaissance d'un mouvement orbital et d'une atmosphère. H. Deslandres. *C. R.* **121**, 629–632, 1895.

The star α Aquilae has some spectral peculiarities which distinguish it from other stars of Vogel's class Ia, in which it is placed by Scheiner. Pickering noticed the uniform diffuseness of the lines, and Scheiner found that, in the region which he investigated, all the characteristic solar groups are faintly reproduced, so that the appearance is that of a faded solar spectrum. In a recent work on stellar spectra (*Pub. d. Astroph. Obs. zu Potsdam*, **7**, II, 232), Scheiner suggests, after considering an alternative explanation of the peculiar spectrum, that α Aquilae is a double star with components of the first and second class, and, although the Potsdam measures give no evidence of orbital motion, he advises that the star should not be lost sight of by spectroscopists. The same explanation, for composite first and second class spectra in general, was given by Pickering (*Ann. H. C. O.* **26**, I, xix.). An argument, which Scheiner justly regards as a strong one, in favor of the duplicity of α Aquilae, is the occurrence of the broad magnesium line at λ 4482, which is never strong in spectra of the second class, though almost invariably so in those of the first.

M. Deslandres, apparently without knowledge of these investigations, has found that α Aquilae is actually a double, or rather multiple star, by spectroscopic observations of its velocity in the line of sight. Fifty-six spectrograms, taken with the four-foot reflector of the Paris Observatory in 1892–5, show a large change of radial velocity with a period of 43 days, on which one or more smaller periodic changes are superposed. The observations are well represented by a secondary oscillation, of which the amplitude and period (about five days) are slightly variable. The star, therefore, should be at least triple; but M. Deslandres considers that a longer series of observations under more favorable circumstances will be necessary, in order to arrive at an exact knowledge of these complicated phenomena in all their phases.

The character of the metallic lines in the spectrum of α Aquilae, although it does not seem to have suggested to M. Deslandres the possibility of the multiple nature of the star, led to another discovery of much interest. It was pointed out by Deslandres some years ago, that bright lines should appear in the solar spectrum, under favorable circumstances, even with an integrating spectroscope. In fact, reversals of H and K, and perhaps some other lines, are found on Rowland's map. It was also pointed out that similar reasoning applied to the stars, and it was the breadth of the metallic lines in α Aquilae that led to its being selected as a test object. Deslandres finds that narrow double bright lines frequently traverse the middle of the dark lines of hydrogen, and sometimes even the lines of calcium and iron. With respect to the continuous spectrum they are of variable intensity. These lines Deslandres attributes to the star's chromosphere. His remark that Altair is the first star in which the special radiations of an atmosphere have been recognized, seems to require several qualifications, unless it can be shown that there is a sharp dividing line between such phenomena as those described above, and the appearances presented by the spectra of stars like ϕ Persei and Pleione.

J. E. K.

Spectrographische Untersuchungen des Saturnringes. A. Bélopolsky. *A. N.* No. 3313, **139**, 1–4, 1895.

In April and May, 1895, Herr Bélopolsky obtained a large number of spectrograms of Saturn with the one prism spectrograph of the Pulkowa Observatory mounted on the photographic refractor. The velocities of different parts of the system of Saturn were determined by measuring, not the inclinations of the spectral lines, but the absolute displacements of points on the lines at a measured distance from the center of the spectrum. The results, which agree well with those obtained at Allegheny, Mt. Hamilton, and Paris, are as follows:

Velocity of equator of Saturn	9.4^{km}	Computed 10.3^{km}.
Velocity of inner edge of ring	21.0	Computed 21.0^{km}.
Velocity of outer edge of ring	15.5	Computed 17.1^{km}.

J. E. K.

Recent Publications.

At the second annual meeting of the Board of Editors of The Astrophysical Journal, recently held at the Harvard College Observatory, it was voted that an attempt be made to increase the scope of the bibliography of astrophysics and spectroscopy published under the heading "Recent Publications." In their present form the monthly lists of recent papers no doubt serve a useful purpose, though they make no claim to completeness. It is evident, however, that a bibliography which derives its titles mainly from the more accessible journals, the annals of the more important societies and the publications of observatories may be of no great value: it should also include publications of obscure origin. Papers of great importance frequently appear in the annals of the smaller societies, or are published at irregular intervals by institutions or individuals. In many cases but few copies of such papers are distributed, and consequently it sometimes happens that contributions of great value are overlooked for years.

It is now proposed that all who are interested in the formation of a complete bibliography of astrophysics and spectroscopy give their assistance by forwarding such titles as come to their notice. The bibliography is intended to cover all investigations of radiant energy, whether conducted in the observatory or in the laboratory. Special mention may be made of photographic and visual observations of the heavenly bodies (other than those pertaining to "astronomy of position"); spectroscopic, photometric, bolometric and radiometric work of all kinds; descriptions of instruments and apparatus used in such investigations; and theoretical papers bearing on any of these subjects.

To those who express themselves as willing to assist in this work cards conveniently arranged for the insertion of titles will be sent. These can be filled out, and mailed to the Journal from time to time. Authors of papers are requested to send copies to Professors Hale and Keeler, in order that the titles may certainly find a place in the bibliography, and also for the purpose of review. If for any reason copies cannot be sent the title alone will serve for insertion in the bibliography.

The following list includes the serial publications from which the

greater part of the titles now appearing in the bibliography are obtained. The abbreviated title is given in a parenthesis following the full title. Where none appears it is understood that the full title is to be used.

The editors will continue to index these publications, and the request for titles therefore applies only to papers not contained in them. This restriction does not include reprints of papers. These will be welcome, from whatever source they may be derived.

Papers, titles, or offers of assistance should be addressed to George E. Hale, Kenwood Observatory, Chicago, or to James E. Keeler, Allegheny Observatory, Allegheny, Pa.

Abhandlungen der K. Akademie der Wissenschaften zu Berlin (Abh. d. K. Akad. d. W. Berlin).

Abhandlungen der K. Bayrischen Akademie der Wissenschaften zu München (Abh. d. K. Akad. d. W. München).

American Chemical Journal (Am. Chem. Jour.).

American Journal of Science (Am. Jour. Sci.).

American Meteorological Journal (Am. Met. Jour.).

Annalen der Physik (Weid. Ann.).

Annales de chimie et de physique (Ann. Chim. et Phys.).

Annales ne l'école normale supérieure (Ann. école norm. supérieure).

Annuaire du Bureau des Longitudes.

Anthony's Photographic Bulletin (Anthony's Photo. Bull.).

Archives des sciences physiques et naturelles (Arch. de Genève).

Archives Néerlandaises des Sciences (Arch. Néerlandaises).

Astronomical Journal (Ast. Jour.).

Astronomische Nachrichten (A. N.).

Astrophysical Journal (Ap. J.).

Atti della R. Accademia di Roma (Atti d. R. Accad. di Roma).

Berichte der Deutschen Chemischen Gesellschaft (Chem. Ber.).

Berichte über die Verhandlungen der K. Sächsischen Gesellschaft der Wissenschaften in Leipzig (Ber. d. K. Gesell. d. W. Leipzig).

British Journal of Photography (Brit. Jour. Photo.).

Bulletin astronomique (Bull. Astr.).

Bulletin de l'académie impériale de St. Pétersbourg (Bull. Acad. St Pétersbourg).

Bulletin de l'académie royale de Belgique (Bull. Acad. R. Belgique).

Bulletin de la société astronomique de France (Bull. Soc. Astr. France.)

Bulletin de la société chimique de Paris (Bull. Soc. Chim. Paris).

Bulletin de la société impériale des naturalistes de Moscou (Bull. Soc. Nat. Moscou).

Chemical News (Chem. News).

Ciel et Terre.

Comptes rendus de l'Academie des Sciences (C. R.).
Electrician.
Elektrotechnische Zeitschrift (Elektrotechn. Zeitschr.).
English Mechanic (Eng. Mech.).
Engineering.
Himmel und Erde (Him. u. Erde).
Jahresbericht der Chemie (Jahresber. d. Chem.).
Johns Hopkins University Circulars (J. H. U. Circulars).
Journal de physique théorique et appliquée (Jour. de Phys.).
Journal für praktische Chemie (Jour. prakt. Chem.).
Journal of the British Astronomical Association (Jour. B. A. A.).
Journal of the Chemical Society of London (Jour. Chem. Soc. London).
Journal of the Franklin Institute (Jour. Franklin Inst.).
Knowledge (Knowl.).
Mathematische und Naturwissenschaftliche Berichte aus Ungarn (Ber. aus Ungarn).
Memoirs of the British Astronomical Association (Mem. B. A. A.).
Memoirs of the Royal Astronomical Society (Mem. R. A. S.).
Memorie della Società degli Spettroscopisti Italiani (Mem. Spettr. Ital.)
Meteorologisches Zeitschrift (Meteorolog. Zeitschr.).
Monthly Notices of the Royal Astronomical Society (M. N.).
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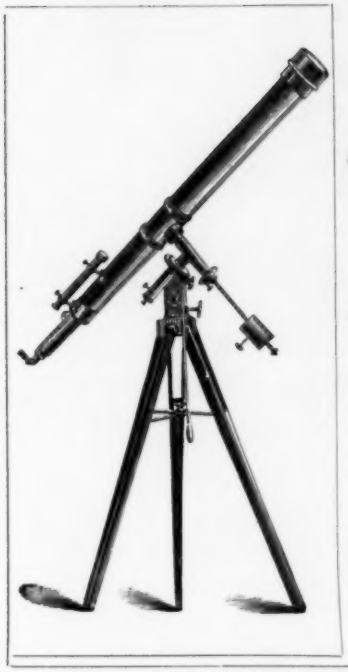

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